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EDITED BY

GEORGE C. LLOYD

SECRETARY



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1925

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GEORGE C. LLOYD.

PREFACE.

THE present volume of the *Journal of the Iron and Steel Institute* contains the Presidential Address of Sir Frederick Mills, Bart., and fourteen papers presented at the Annual Meeting held in London, with the discussion and correspondence thereon. It also contains a report of the proceedings and speeches at the Annual Dinner held at the Hotel Cecil on May 7.

Biographical notes of the careers of members deceased will be found under "Obituary Notices."

Section II. contains, as usual, notes on the progress of the home and foreign iron and steel industries, as reported in the proceedings of scientific and technical societies and in the technical press, together with a short review of new books presented to the Institute, and a bibliography of the principal works dealing with the metallurgy of iron and steel and allied subjects, which have appeared during the past six months.

At the end is inserted a list of the British Standardised Steel Samples issued jointly by the Iron and Steel Institute and the National Physical Laboratory showing where and on what terms the samples are obtainable.

28 VICTORIA STREET, LONDON, S.W. 1.

August 31, 1925.

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THE
IRON AND STEEL INSTITUTE.

SECTION I.
MINUTES OF PROCEEDINGS.

ANNUAL MEETING, 1925.

THE FIFTY-SIXTH ANNUAL GENERAL MEETING of the IRON AND STEEL INSTITUTE was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday and Friday, May 7 and 8, 1925, under the Presidency of Sir WILLIAM ELLIS, G.B.E., D.Eng.

FIRST DAY (*Thursday, May 7*).

The Minutes of the last General Meeting were taken as read and confirmed.

SCRUTINEERS.

Mr. N. D. RIDSDALE (Middlesbrough) and Mr. P. GOUGE (Paris) were appointed scrutineers of the ballot for the examination of the voting papers, and they subsequently announced that the following forty-five candidates for membership and five candidates for associateship had been duly elected.

MEMBERS.

NAME.	ADDRESS.	PROPOSERS.
Alberti, Ing. Alforisio	110 Viale B. Brin, Terni, Italy	H. Shillitoe, G. Ciompi, A. Piccioli.
Barr, William . .	Sudbury, Larkhall, Lanarkshire	J. H. Andrew, R. Higgins, R. S. Wilson.
Blagden, Arthur . .	The Angus Co., Ltd., Angus Laboratories, P.O. Angus, District Hooghly, E.I. Railway, Bengal, India	T. G. Arnold, A. A. Bryant, G. Grant.
Bullen, Frederick John, O.B.E.	39 Victoria Street, London, S.W. 1	F. W. Cooper, P. S. J. Cooper, N. D. Chopra.
Burton, Geoffrey Duke, B.A. (Cantab.)	C/o Earl of Dudley's Round Oak Works, Ltd., Brierley Hill, Staffordshire	G. Hatton, C.B.E., J. W. Trowshale, W. H. B. Hatton.
Conway, Martin John	323 South Fifth Street, Steubenville, Ohio, U.S.A.	O. L. Pringle, T. F. Foss, F. Crabtree.
Coste, Emilio . . .	Calle Ibañez de Bilbao 6 3° Bilbao, Spain	L. de Olazabal, V. Balanzategui, Luis Barreiro.
Cotnareanu, Ionel . .	Société Petrometal, 10 rue des Messageries, Paris	H. A. Scott Barrett, H. Beard, H. Fernihough.
Cotnareanu, Philippe	Société Petrometal, 10 rue des Messageries, Paris	H. A. Scott Barrett, H. Beard, H. Fernihough.
Dearden, Wm. Hoghton, M.Sc.	Royal School of Mines, South Kensington, S.W. 7	H. C. H. Carpenter, F. C. Thompson, Miss C. F. Elam.
Foley, Francis B., M.Am.Inst.M. and M.E.	Lucey Manufacturing Corporation, Chattanooga, Tenn., U.S.A.	C. Y. Clayton, J. A. Capp, S. L. Hoyt.
Harley, Herbert Harry	Coventry Gauge & Tool Co., Ltd., Warwick St., Coventry	F. C. A. H. Lantsberry, F. L. Warren, E. M. Boote.
Holden, John Whittle	29 Manor Court Road, Hanwell, W. 7	Sir R. A. Hadfield, Bart., A. B. H. Clerke, W. J. Dawson.
Iytaka, Ityrô . . .	C/o Mitsubishi Research Laboratory, 29 Komagome - Kamifu - jimaechô, Hongô-ku, Tokyo, Japan	K. Tawara, T. Kawamura, T. Murakami.
Jacks, Harold Benjamin	Berrington, Selly Park Road, Birmingham	Sir W. C. Wright, K.B.E., Sir Wm. Ellis, G.B.E., F. W. Harbord.
Jeffries, Zay, S.D. .	Aluminium Company of America, 2800 Harvard Avenue, Cleveland, Ohio, U.S.A.	H. A. Schwartz, J. V. Emmons, H. M. Boylston.
Jenkins, Charles Henry Morris	10 Gatestone Road, Upper Norwood, London, S.E. 19	H. C. H. Carpenter, W. Rosenhain, D. Hanson.

NAME.	ADDRESS.	PROPOSERS.
Lewis, Alfred Cecil, B.Sc. Met. (Birm.)	Craiglas, Talybont-on- Usk, Breconshire	Sir F. Mills, Bart., F. P. Hann, R. Graham.
Mackay, William	7 The Clachan, Kenil- worth Avenue, Wishaw, N.B.	R. S. Wilson, J. H. Andrew, J. A. C. Edmiston.
Malhotra, Des Raj, S.B. (Harvard)	Aminpur Street, Lyallpur, Punjab, India	G. B. Waterhouse, A. Sauveur, E. L. Reed.
Malone, Cyril Antony	59 Marlborough Road, Broomhill, Sheffield	A. S. Pye-Smith, F. A. Hurst, E. Pasley.
Matthews, Henry Idris, B.Sc.	The Rifle Factory, Isha- pore, E.B. Railway, India	H. C. H. Carpenter, E. F. Law, W. H. Merrett.
Meissner, Carl August, M.Sc.	C/o United States Steel Corporation, Room 1901, 71 Broadway, New York, U.S.A.	C. F. Rand, Q. Bent, H. A. Brassert.
Monasteria, Antonio	Beasain (Guipuzcoa), Spain	Sir Wm. Ellis, G.B.E., A. Lucio-Villegas, R. Quijano.
Moyna, J.	United Engineers Limited, Singapore	P. L. Martyn, R. H. M. Rowe.
Nespral, Secundino Felgueroso F.	La Felguera (Asturias), Spain	A. de Churruca, R. Quijano, A. Lucio-Villegas.
Nutt, Frederic Swin- ton	22 Henry Road, Chelms- ford, Essex	G. D. Flather, D. Flather, J. E. Miller.
Osborn, Ian Samuel, B.A. (Camb.), Eng.	15 Endcliffe Hall Avenue, Sheffield	A. Pye-Smith, A. S. Pye- Smith, F. A. Hurst.
Parkes, Arthur Israel	39 Augustus Road, Edg- baston, Birmingham	G. Hatton, T. Turner, H. A. Davies.
Pišek, Dr. Mont František	Technical High School, Brno, Czechoslovakia	A. Křiž, N. Belaiew.
Preece, Frank Hugh, A.M.Inst.C.E.	C/o Messrs. Babcock & Wilcox, Ltd., Babcock House, Farrington St., E.C.	A. Hall-Brown, G. H. Fraser, A. G. C. Gwyer.
Renton, Charles Yea- man	The Limes, Psalter Lane, Sheffield	B. M. Renton, G. E. Griffith, F. Turton.
Richardson, Richard John	Llanblethian House, near Cowbridge, Glamorgan- shire	A. O. Morgan, A. R. Roberts, H. Davies.
Scott, Louis G.	Messrs. E. G. Acheson, Ltd., 40 Wood Street, London, S.W. 1	H. Brearley, P. B. Henshaw, V. C. Faulkner.
Shaw, Frederick W.	3 Peel Terrace, Wilkinson Street, Sheffield	W. H. Hatfield, J. W. Fawcett, J. A. Clements.
Smith, Earle C.	Central Steel Company, Massillon, Ohio, U.S.A.	H. C. H. Carpenter, M. J. R. Morris, Sir Wm. Ellis, G.B.E.
Taylorson, Ewart S., B.S.	1410 Frick Building, Pitts- burgh, Pa., U.S.A.	J. M. Camp, C. F. W. Rys, H. P. Tiemann.
Tucker, Percy A.	Braemon, Little Green Lane, Erdington, near Birmingham	F. W. Harbord, C.B.E., E. F. Law, T. Vickers.

NAME.	ADDRESS.	PROPOSERS.
Uhlein, Robert F.	210 Elm Street, Cincinnati, Ohio, U.S.A.	J. A. Mathews, A. H. Kingsbury, Sir Wm. Ellis, G.B.E.
Valentine, Joseph William	Tata Iron & Steel Co., Ltd., Jamshedpur, <i>via</i> Tananagar, B.N.R., India	T. W. Graham, F. B. Cawley, G. J. Valentine.
Walker, Alfred	The North Lincolnshire Iron Co., Ltd., Scunthorpe	A. Lennox Leigh, G. Barrett, James H. Parker.
Weesner, C. W.	219 Ridgeway Avenue, Warren, Ohio, U.S.A.	G. F. Comstock, W. Campbell, H. C. Boynton.
White, John Grove, Assoc.M.Inst.C.E.	Jamalpur, E.I.R., India	J. A. Smeeton, L. J. Swift, Sir W. Stokes.
Willett, Samuel Walter	Tata Iron & Steel Co., Ltd., Jamshedpur, India	R. Mather, A. A. Bryant, J. L. Keenan.
Woodcock, Francis Stanley, A.M. Inst. C.E., A.M.I. Mech.E.	Ebbw Vale Steel, Iron & Coal Co., Ltd., 1 Victoria Street, London, S.W. 1	Sir F. Mills, Bart., Sir R. A. Hadfield, Bart., Sir Wm. Ellis, G.B.E.
ASSOCIATES.		
Everest, Arthur Bernard, B.Sc.	46 Clifton Road, Rugby	T. Turner, T. H. Turner, L. Northcott.
Foster, Vivian Thomas Smith	Asthal House, Abergavenny, Monmouthshire	C. H. Desch, T. F. Russell.
Murray, David, B.Sc. (Eng.)	"Muirend," Wilson St., Motherwell	J. H. Andrew, R. Higgins, R. S. Wilson.
Nix, Foster Cary	Box 412, Rolla, Mo., U.S.A.	C. Y. Clayton, G. K. Burgess, D. A. Lyon.
Russell, Henry Baltantyne	26 Nelson Place, Stirling	J. H. Andrew, R. Higgins, M. S. Fisher.

REPORT OF COUNCIL.

The SECRETARY read in abstract the Report of the Council for the year 1924, the full text of which will be found on pp. 16-26.

The PRESIDENT offered a very cordial welcome from the members to Dr. Benedicks, one of the Honorary Vice-Presidents of the Institute. Dr. Benedicks had recently returned from a visit to the United States, where he had given a series of lectures, and it was a great pleasure to the members to see him present at the meeting that morning.

STATEMENT OF ACCOUNTS.

Mr. ILLTYD WILLIAMS (Hon. Treasurer) presented the Balance Sheet and the Statement of Accounts for the past year (see pp. 27-30).

The Income and Expenditure Account showed a balance in favour of the former of practically £500, but that figure put the case in too favourable a light, because there had been brought into the receipts a sum of £177 odd which remained as a surplus after closing the accounts relating to the Autumn Meeting held in Italy in the year 1923. By the generosity of the members who took part in that meeting, that surplus had fallen into the General Account. The actual surplus due to the year's work was £329 19s. 4d., and it was gratifying to know that, as in each of the two preceding years, the margin, even if small, had been on the right side. A satisfactory feature on the expenditure side was the lower cost of journal publishing, an item which had been very high for some years past. No change had been made in the investments on behalf of the various accounts during the year, but the Council some little time ago had decided to strengthen the Life Composition Fund by investing all sums received from members compounding their subscriptions until such time as there was a fair certainty that the Fund was adequate to meet the liability of the Institute to its Life Members. The market values at December 31, 1924, of the investments on account of the General Fund and on account of the Life Composition Fund, still showed heavy depreciation when compared with the cost prices, but in the cases of the Carnegie Trust and the Special Purposes Fund the position was more satisfactory, the depreciation in the former case being less than one-half per cent., while the latter case showed a fair appreciation. He hoped that financially the result of 1925 might be equal to that of its predecessor, although the position was not without a certain amount of uncertainty and anxiety.

On the motion of the PRESIDENT, seconded by Mr. J. H. HARRISON (Middlesbrough), the Balance Sheet and Statement of Accounts were unanimously adopted.

INDUCTION OF THE NEW PRESIDENT.

The PRESIDENT said that Sir Frederick Mills, who was about to take his place in the Chair, was well known, not only to all the members, but in the industrial life of the country, and it was unnecessary for him to express to Sir Frederick their full confidence in his personality, his ability, and his knowledge in taking up the Presidency of the Institute. Sir Frederick and himself had agreed between themselves to say very little on the subject, and personally he proposed honourably to carry out that contract. Some papers of considerable importance, which would be most useful to the scientific side of the Institute, were about to be read. It had been decided to hold the Autumn Meeting in Birmingham, for which arrangements were being made by Mr. Hatton, Professor Turner, and Mr. Jacks. A series of very interesting visits would be made, and assurances had been received that a good many of the members would attend the meeting. He desired to congratulate Sir Frederick on being elected to the high office of President. Sir Frederick would take the Chair with a feeling of confidence on the part not only of all his colleagues on the Council, but, he believed, of the members in general; and the fact that he would occupy the Presidency for the ensuing year would, he hoped, be a source of much gratification to him. On behalf of all the members he wished Sir Frederick every success in the Presidential Chair, which he now asked him to occupy.

[The Chair was then vacated by Sir William Ellis, and taken, amid very hearty applause, by Sir Frederick Mills, Bart., D.L., M.Inst.C.E., M.I.Mech.E.]

SIR FREDERICK MILLS, on taking the Chair, said he intended to carry out his part of the contract with Sir William to the very fullest extent. He desired in the first place to thank his colleagues on the Council for their confidence in conferring upon him the honour of Presidency of their world-famous Institute, and in view of the measure of applause with which he had been greeted on taking the Chair, he thanked the members for their confidence

in him also. He hoped during his year of office to justify that confidence.

Sir ROBERT HADFIELD, Bart., F.R.S. (Past-President), said he was sure the members would not desire to proceed further with the programme of the meeting without first offering their heartiest thanks to Sir William Ellis for his able conduct in the Chair during his term of office. He believed he could take a little credit to himself for having persuaded Sir William to continue as a member of Council and eventually to take the Chair, which he had filled so admirably. On the previous evening the Council Dinner to the retiring President was held, and he wished the members in general could have heard the terms, not only of respect, but of affection, with which Sir William was regarded. Sir William's father, Mr. J. D. Ellis, had been one of the oldest members of the Institute, and it had been largely through his help that the Institute had paid the memorable visit to Sheffield in 1905, which was still considered as one of its records. As one of the senior members of the Council it was a great pleasure to him to propose the vote of thanks, which he was sure would be most heartily accorded. He further desired to offer on behalf of the members their very best wishes and congratulations to Sir William on the fact that he was about to enter upon another very important post. Sir William would step out of one Presidential Chair into another, and if he filled the Presidential Chair of the Institution of Civil Engineers with the same success that had attended his efforts in the Chair of the Iron and Steel Institute, he would be performing a great service to the Institution of Civil Engineers. With the vote of thanks to Sir William for his past services he would couple the members' best wishes for his success in the new office which he was about to undertake.

The resolution was then put and carried by acclamation.

Sir WILLIAM ELLIS, G.B.E., D.Eng. (Past-President), desired very cordially to thank the members for the hearty manner in which they had received Sir Robert Hadfield's remarks. At the Council Dinner held on the previous evening it was quite correct, as Sir Robert had stated, that a very warm feeling was expressed

towards himself, which he appreciated very fully. He hoped his colleagues on the Council appreciated how deeply he felt their kindness. Sir Robert had further alluded to impending events. As a matter of fact, the statement in regard to stepping from one Presidential Chair into another was not quite accurate, as the Chair happened to be the same one. Such responsibilities were indeed serious matters. Sir Robert had alluded to his hesitation in taking the Presidency of the Institute. That feeling was very largely influenced by the fact that he knew the Presidency of the Institution of Civil Engineers was likely to be offered to him, and he therefore had doubts as to whether he ought to undertake both tasks. He hoped and believed, however, that the Presidency of the Institution of Civil Engineers being held by one who had just vacated the Presidency of the Institute might not be without credit to the Institute, as showing that there was that close association between metallurgy and engineering that ought to exist in this country and that ought to be increased as far as possible, because progress would result from close co-operation between the leading metallurgists and leading engineers of the country. He warmly thanked his colleagues on the Council and the members for their kindness and support while he had occupied the Chair. His tenure of the office was one of the turning-points in his life, and he left the Chair with delightful memories and pleasant associations.

PRESENTATION OF THE BESSEMER GOLD MEDAL.

The PRESIDENT said that his first duty as President was to make the award of the Bessemer Gold Medal, and it was his very great pleasure to confer that medal in the name of the Institute on Professor Turner, in recognition of his distinguished services to the advancement of the science of the metallurgy of iron and steel. For many years Professor Turner's name had been familiar to the members as Professor of Metallurgy at Birmingham University, and as the head of a department which had become famous for its metallurgical researches, and prolific in publications dealing with many branches of ferrous and non-ferrous metallurgy. Among those assembled there that day to do

honour to Professor Turner there were doubtless many who owed to him their instruction in metallurgical science, which had enabled them in after life to take prominent positions in the scientific or industrial world ; while there were others there who, perhaps not having had the privilege of studying under his immediate guidance, had nevertheless benefited greatly by the results of his investigations in the field of metallurgy.

In particular, he might call to mind Professor Turner's early researches on the influence of silicon on the properties of cast iron, the results of which had met with immediate and wide application. Professor Turner's studies of the effect of each of the elements which were present in cast iron had been said to have laid the foundation of scientific iron-founding. That in itself was a great and worthy achievement, but Professor Turner had not rested there. It would be beyond him (the President) to recapitulate the nature of all Professor Turner's investigations, but he would say that they included studies on the formation and varieties of graphite in cast iron, on the microstructure of castings, on the changes in volume during solidification, on the influence of the rate of cooling, and of casting temperatures, not to mention the nature and properties of metals other than iron and steel, on which a vast amount of work had been expended, including the invention and design of a sclerometer for the purpose of testing their hardness.

As the members all knew, Professor Turner had already been the recipient of many well-deserved honours. It was too much to attempt to enumerate them all, but he might say that Professor Turner had been President of the Staffordshire Iron and Steel Institute, and was at the present time President of their kindred Society, the Institute of Metals. They also had the privilege of having him as a member of their own Council. He was Honorary Member of a number of Metallurgical Societies in the Dominions and in foreign countries. Birmingham had recently manifested its appreciation of him by the establishment of a Trust for the award of Thomas Turner Gold and Bronze Medals, and prizes for metallurgy, in the University of Birmingham.

He had the greatest pleasure in handing to Professor Turner the Bessemer Medal, which was a token of the highest honour it was in the capacity of the Institute to confer, and he did so with

congratulations, and with the hearty good wishes of all Professor Turner's colleagues and friends there assembled.

[The PRESIDENT then presented the Medal to Professor Thomas Turner.]

Professor THOMAS TURNER, in acknowledging the presentation, said it was a great honour to receive the Bessemer Gold Medal of the Iron and Steel Institute—an honour which not only he appreciated, but also his family, many students in various parts of the world, and his University. All people were more or less hero-worshippers, and Bessemer was certainly one of his heroes. It had been his pleasure on various occasions to lecture on the life and work of Sir Henry Bessemer, who was a remarkable man, apart altogether from the great discovery with which the Institute was more particularly associated. It was a long time since he (Professor Turner) attended his first meeting of the Iron and Steel Institute, namely, in 1885. He was a visitor on that occasion, and he was surprised to find that the members were engaged in discussing some work of his own on the influence of silicon on cast iron. His old friend, a Past-President of the Institute, Dr. Stead, was reading the paper and, with all the assurance of youth, he (Professor Turner) joined in the discussion, and ventured to express views which were not in accord with those of Sir Lowthian Bell, that eminent metallurgist, who was then in his prime. Another great man was connected with the Institute at that time, namely, Dr. Percy, who was the then President. He consulted Dr. Percy in the early days of his (Professor Turner's) own membership as to whether or not he might venture to read a paper before the Institute, being then very young. Dr. Percy's reply was that the greater part of the work of the world was done by young men. So encouraged he drafted a paper and submitted it to Dr. Percy before it was read to the Institute. When the paper was read Sir Henry Bessemer was present and listened with interest to it. He afterwards came up to him and, in the very kindest way, shook hands with him and expressed his congratulations. He need not say that such an action on the part of so eminent a man was highly appreciated by the young research worker. There was much in a hand-shake; it often revealed the character of a man.

He always remembered the shake of the hand that he received from Sir Henry Bessemer. There was a firmness and gentleness about it which expressed, he thought, symbolically, Sir Henry's remarkable artistic capacity and his skill as a craftsman. Apart altogether from the honour which the Institute had been good enough to confer upon him, it was a great pleasure to him to have his name associated in that way with that great English metallurgist and inventor.

PRESIDENTIAL ADDRESS.

The PRESIDENT then delivered his Presidential Address, the text of which will be found on p. 31.

After concluding his address, the President informed the meeting that he had just paid a very interesting visit to the Hagfos Works of the Uddeholms Aktiebolag in Sweden, where he saw mild steel made in an electric arc furnace direct from iron ore.

The ore so far used was concentrate, containing 65 to 70 per cent. of iron, which was mixed with 22 per cent. of fine coal and 10 per cent. lime. 2500 kilowatt-hours per ton were required for the whole process of reduction and refining. The resulting steel was quite fluid and of good quality. He had a sample of the briquette and of the steel, which members could, if they cared, examine. The process was admittedly in its experimental stage: the questions of speed and of economy remained to be demonstrated; but the company had dismantled one of its modern electric smelting furnaces, and had decided to install in its place a new unit to test those questions. He had been impressed by what he had seen, and if the figures of cost, both capital and manufacturing, given to him were confirmed by results, the process would effect a revolution in steel-making which would have far-reaching effects. He wished to sound a few words of caution: fifty years ago Sir William Siemens made steel in an arc furnace; he also made steel from iron ore direct in a regenerative furnace. Had Mr. Flodin, he wondered, at long last justified Dr. Siemens' expectations? That would be a revolution indeed! Was it possible to picture a steel-making centre where the low-temperature carbonisation of coal would provide gas for gas engines, smokeless fuel for manufacturing and household purposes, and

electricity for making steel direct, without the intervention of blast-furnaces and pig iron? He hoped the inventor would soon be in a position to present the results of his experiments to the Institute in the form of a paper. In the meantime, in view of the possibilities, he thought the matter of sufficient importance to bring immediately to the notice of the members.

Lord INVERNAIRN (Past-President) said the members had just listened to a most sound, practical, and interesting address from the President, which he was sure they would all greatly value and appreciate. He therefore had much pleasure in proposing that a hearty vote of thanks be accorded to the President for that valuable and interesting address.

The resolution was then put and carried by acclamation.

The PRESIDENT having briefly acknowledged the compliment, the following papers were then read and discussed :

MORNING SESSION.

- T. W. HAND, "Progress in British Rolling-Mill Practice."
A. HULTGREN, "Flakes or Hair Cracks in Chromium Steel, with a Discussion on Shattered Zones and Transverse Fissures in Rails."

AFTERNOON SESSION.

- T. HENRY TURNER and J. D. JEVONS, "The Detection of Strain in Mild Steels."
J. D. JEVONS, "Strain Detection in Mild Steel by Special Etching."
A. G. LOBLEY and C. L. BETTS, "The Influence of Gases at High Temperatures upon Iron, with Special Reference to the Formation of Blowholes."

CARNEGIE SCHOLARSHIP AWARDS.

On the resumption of the meeting on the morning of Friday, May 8, the SECRETARY read the following Report from the Carnegie Scholarship Committee, which had been unanimously adopted by the Council.

Applications for grants were received from eight candidates, and, after careful investigation of all the applications, the Committee recommended that grants be awarded to all the candidates, and the Council approved the amounts of each grant as follows :

- W. CRAFTS (Reading, U.S.A.), £100, to carry out a research on the production of carbonless chromium by the method of leaching and electrolytic deposition of chromium from chromite.
- W. H. DEARDEN (London), £100, to study the specific heat of iron below 400° C.
- T. H. TURNER and E. W. FELL (Birmingham), £100 jointly, to investigate methods of detection and the nature of permanent deformation or strain in steels.
- R. HIGGINS (Glasgow), £100, to study the volume changes in cast iron brought about by repeated heating and cooling.
- H. O'NEILL (Manchester), £100, to study the nature of hardness in relation to cold-working and machining properties of metals.
- J. H. PARTRIDGE (Birmingham), £50, to investigate the electric and magnetic properties of cast iron.
- L. B. PFEIL (Swansea), £100, for a study of the growth of large crystals by annealing strained iron, including the properties of such crystals.

It was also recommended that further grants be made to the four following investigators :

- C. H. ADAMSON and G. S. BELL (Sheffield and Lincoln), £50, to continue their research on transverse cast-iron test-bars.
- D. W. BERLIN (Rasunda, Sweden), £50, to study the specific gravity of liquid iron.
- A. L. CURTIS (Chatteris, Cambs.), £50, to assist his investigation on steel moulding sands.
- E. R. TAYLOR (Birmingham), £50, to continue his study of the effect of manganese and sulphur on the properties of malleable cast iron.

The following papers were then read and discussed :

- R. H. GREAVES and J. A. JONES, "Temper-Brittleness of Steel; Susceptibility to Temper-Brittleness in Relation to Chemical Composition."
- W. T. GRIFFITHS, "Note on Nitrogen as a Possible Factor in Temper-Brittleness."
- D. H. INGALL and H. FIELD, "'Peeling' in White-Heart Malleable."
- R. L. SMITH and G. E. SANDLAND, "Some Notes on the Use of a Diamond Pyramid for Hardness Testing."
- B. D. ENLUND, "On the Structure of Quenched Carbon Steels."
- J. H. WHITELEY, "Observations on Martensite and Troostite."

The following papers were taken as read :

- L. AITCHISON and L. W. JOHNSON, "The Effect of Grain upon the Fatigue Strength of Steels."
- H. VON ECKERMANN, "A Method for Reducing the Percentage of Phosphorus in Swedish Iron by Diminishing the Phosphorus in the Charcoal."
- G. WATSON GRAY and C. D. GARBUTT, "Estimation of Phosphorus in the Presence of Vanadium."

The PRESIDENT said that before closing the meeting he wished to propose a vote of thanks to the Institution of Civil Engineers, in whose beautiful building the meeting was being held, for the loan of the hall. The Secretary would convey the resolution to the Secretary of the Institution of Civil Engineers.

The motion having been carried unanimously,

Sir ROBERT HADFIELD, Bart., F.R.S. (Past-President), said the members would not wish to part without expressing their very hearty thanks to the President for so ably presiding. Sir Frederick Mills had given a most wonderful address on the previous day, drawing attention to many points, and, if he (Sir Robert) might venture to say so in the presence of so many experts, to one point of perhaps the greatest importance—he referred to the remarks on the industrial position. All present had greatly enjoyed hearing the President's address on a subject which was attracting much attention at the present time. Government help was not required, but it was desired that the Government should take an intelligent and friendly interest in helping, if at all possible, the metallurgical industries of the country. Things were really in a very serious condition. The members were much indebted to the President for drawing attention to that most important aspect of one of the greatest industries of the country.

The motion for the vote of thanks to the PRESIDENT having been carried with acclamation,

The PRESIDENT, in reply, thanked Sir Robert Hadfield for his approval of the particular line that had been taken in the address.

He had taken that line with some fear and trepidation, because it was distinctly against the rules and regulations of the Institute. The present meeting was the first occasion on which he had sat out the whole of the proceedings of the Institute, and he was a little undecided as to whether he was glad or sorry that he had not on previous occasions followed the wonderful discussions that took place at those meetings. He did not know whether he was to be condoled with on having missed so much or congratulated on having been spared so much in regard to subjects about many of which he confessed he knew nothing at all. Works managers had not much opportunity of giving attention to such matters, but he admired the magnificent work that was being done by the young metallurgists, not only in Great Britain, but all over the world. He greatly appreciated the presence of American and Swedish friends who had come to London to take part in the discussions ; it showed that science, like art, knew no boundaries, and that, whatever might happen in the world of politics and in the world of industry, they were all friends when it came to the realm of science.

The proceedings then terminated.

REPORT OF COUNCIL.

THE Council of the Iron and Steel Institute have much pleasure in submitting for the approval of the members at this, the Fifty-sixth Annual General Meeting, their Report on the proceedings and work of the Institute during the year 1924.

ROLL OF THE INSTITUTE.

During the past year ninety-nine new members and sixteen associates were elected, and nine associates were transferred to membership; and the total membership of the Institute on the register on December 31, 1924, was as follows :

Patron	1
Honorary Members	11
Life Members	80
Ordinary Members	1964
Associates	37
<hr/>	
Total	2093

Seventy members and one associate resigned their membership during the year, and the names of forty-three members and five associates were removed from the register owing to the non-payment of their subscriptions.

The deaths of the following twenty-six members occurred during the year, and have been reported to the Council :

Agius, E. T. (London)	September 21.
Beilby, Sir G. T. (London)	August 2.
Burls, H. T. (London) (Life Member)	April 16.
Coe, H. I. (Swansea)	February.
Colby, A. L. (Bethlehem, U.S.A.)	May 1.
Corning, C. R. (New York)	July 2.
Cremer, J. H. (Cleveland, U.S.A.)	July 20.
Crooke, W. (Frodingham)	June.
Crowe, E. (Saltburn-by-the-Sea)	June.
Dellwick, Carl (Chorley Wood)	December 12.
Gregory, J. (Singhbhum, India)	April.
Hamilton, J. (Cambuslang, N.B.)	June.
Houghton, J. (Lymm)	December 15.

Hughes, J. W. (London)	August 11.
Lauder, G. (Pittsburgh, U.S.A.)	August 24.
Lisboa, M. A. (Lausanne)	Not known.
Martin, T. C. (New York) (Life Member)	May 17.
Maw, W. H. (London)	March 19.
Meunier, L. (Le Blanc)	January 28.
Morgan, A. H. (London)	September 29.
Morris, W. H. (Philadelphia)	January 11.
Richards, E. J. Windsor (London)	August 5.
Sterne, L. (London)	May 29.
Tucker, A. E. (Birmingham)	March 28.
Vitali, G. (Turin, Italy)	April 4.
Woof, T. (London)	April 25.

The deaths of the following three members occurred prior to 1924, but were not reported to the Council until that year :

Moss, C. H. (Rotherham)	March 1923.
Petre, A. E. (Stockholm)	December 23, 1923.
Preston, H. J. (Kettering)	December 27, 1923.

The Council wish to place on record their sense of the loss to the Institute, and to scientific metallurgy in general, incurred through the death of Sir George T. Beilby, F.R.S. Mr. H. T. Burls was a Life Member of the Institute and a familiar figure at its meetings. Mr. Louis Sterne and Mr. E. J. Windsor Richards were also well-known and faithful supporters; whilst among the foreign members of the Institute the loss of Comm. Ing. G. Vitali of Turin and Mr. T. Commerford Martin of New York will be deeply regretted by their many friends.

HONOURS CONFERRED ON MEMBERS OF THE INSTITUTE.

The Council have much pleasure in congratulating several members of the Institute who have had appointments of distinction conferred on them during the year. Sir William Ellis, G.B.E., D.Eng., has been appointed a member of the Advisory Council to the Committee of the Privy Council for Scientific and Industrial Research. Colonel J. G. Needham, D.S.O., O.B.E., has been appointed Deputy-Lieutenant of the County of Lancaster, and Professor William Campbell has been appointed to the Howe Professorship of Metallurgy of Columbia University, New York. The Perkin Medal of the Society of Chemical Industry has been awarded to Mr. F. M. Beckett, and the Graselli Medal of the American Society of Chemical Industry has been awarded to

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Mr. B. D. Saklatwalla. The Le Blanc Medal for Electro-Chemistry has been awarded to Mr. B. K. Braund, and Mr. G. K. Lemmy has been made an Officier de l'Instruction Publique. Mr. J. G. Pearce has been appointed Director of the British Cast Iron Research Association.

FINANCE.

The Statement of Accounts for the year 1924 which accompanies this Report is presented by Mr. Iltyd Williams, Hon. Treasurer, for approval, after having been duly audited and certified by Messrs. W. B. Keen & Co., the Institute auditors. The income for the year under review was £8068, exclusive of the Carnegie Scholarship Fund and of the interest received from investments constituting the Special Purposes Fund, and the expenditure for the year was £7568. The comparative figures of income and expenditure for the last five years are shown below :

				Income.	Expenditure.
				£	£
1919	.	.	.	5979	7088
1920	.	.	.	8419	7622
1921	.	.	.	8349	6866
1922	.	.	.	7964	7939
1923	.	.	.	8095	8012

MEETINGS.

The Annual Meeting of the Institute was held by kind permission of the Council of the Institution of Civil Engineers at the House of that Institution on Thursday and Friday, May 8 and 9, the chair being taken by the President, Sir William Ellis, G.B.E., D.Eng.

The Annual Dinner was held at the Hotel Cecil on the evening of Thursday, May 8, and was attended by some 300 members and guests. Speeches were delivered by Sir Hugh Bell, Bart., C.B., Past-President ; the Right Hon. Viscount Chelmsford, K.C.M.G., First Lord of the Admiralty ; the Right Hon. Lord Stuart of Wortley ; the President ; Mr. John Craig, C.B.E. ; His Excellency C. R. Paravicini, the Swiss Minister ; and the Right Hon. Sidney Webb, M.P., President of the Board of Trade.

The Autumn Meeting of the Institute was held at the British Empire Exhibition, Wembley, on September 4 and 5, and was numerously attended. On the evening of Wednesday, September 3, a reception of the members was held by the President at the new Princes' Galleries, Piccadilly, a musical entertainment being provided after the reception.

Twenty-seven papers were contributed to the proceedings of the Institute during the year, and have been reprinted, together with the discussions and correspondence thereon, in the Journal. The complete list is as follows :

- AITCHISON, L., and L. W. JOHNSON—"Notes on the Testing of Metal Strip."
- AITCHISON, L., and G. R. WOODVINE—"The Changes of Volume of Steels during Heat Treatment."
- ANDREW, J. H., and H. HYMAN—"High-Temperature Growth of Special Cast Irons."
- ARROWSMITH, R.—"Note on the Effect of Grain-Size on the Extension at the Yield Point in Armco Iron."
- BEDSON, J. P.—"Continuous Rolling-Mills: their Growth and Development."
- BELL, G. S., and C. H. ADAMSON—"Transverse Test-Bars and Engineering Formulæ."
- BENEDICKS, C., and V. CHRISTIANSEN—"Investigations on the Herbert Pendulum Hardness Tester."
- CAMPBELL, E. D., and G. W. WHITNEY—"The Effect of Changes in Total Carbon and in the Condition of Carbides on the Specific Resistance and on some Magnetic Properties of Steel."
- COLBECK, E. W., and D. HANSON—"The Hardening of Silico-Manganese Steels."
- DYRSSEN, W.—"Recovery of Waste Heat in Open-Hearth Practice."
- EDWARDS, C. A.—"Pickling; or, the Action of Acid Solutions on Mild Steel and the Diffusion of Hydrogen through the Metal."
- EDWARDS, C. A., and L. B. PFEIL—"The Production of Large Crystals by Annealing Strained Iron."
- FRIEND, J. NEWTON, and W. E. THORNEYCROFT—"Examination of Iron from Konarak."
- GROSSMANN, M. A., and E. C. BAIN—"On the Nature of High-Speed Steel."
- HINDLEY, W. N.—"Some Effects of the Penetration of Arsenic and Sulphur into Steel."
- HONDA, K.—"On the Forging Temperature of Steels."
- HONDA, K., and K. TAKAHASI—"On the Indentation Hardness of Metals."
- HULTGREN, AXEL—"Improvements in the Brinell Test on Hardened Steel, including a New Method of Producing Hard Steel Balls."
- MACNAUGHTAN, D. J.—"The Hardness of Electro-Deposited Iron, Nickel, Cobalt, and Copper."
- NORBURY, A. L., and T. SAMUEL—"Experiments on the Brinell-Tensile Relationship."
- O'NEILL, H.—"The Effect of Cold-Work upon the Density of α -Iron."
- ROSENHAIN, W.—"The Hardening of Steel."
- SEIGLE, J.—"Theoretical Considerations respecting Certain Features in the Working and Efficiency of Reversing Regenerators."
- THOMPSON, F. C., and W. E. W. MILLINGTON—"The Plastic Deformation of α - and γ -Iron."
- THOMPSON, F. C., and W. E. W. MILLINGTON—"The Effect of Free Surfaces on the Plastic Deformation of Certain Metals."

WESTGREN, A., and G. PHRAGMÉN—"X-Ray Studies on the Crystal Structure of Steel. Part II."

Ferrous Alloys Research.—Part I.—Introduction. By WALTER ROSENHAIN, D.Sc., F.R.S.; Part II.—Iron and Oxygen. By F. S. TRITTON and D. HANSON, D.Sc.; Part III.—The Estimation of Oxygen in Pure Iron. By T. E. ROONEY.

The following reports have been published as Volume XIII. of the Carnegie Scholarship Memoirs :

ANDREW, J. H., and A. J. K. HONEYMAN—"Specific Volume of Steels."

BENEDICKS, C., D. W. BERLIN, and G. PHRAGMÉN—"A Method for the Determination of the Specific Gravity of Liquid Iron and Other Metals of High Melting Point."

ELLIS, O. W.—"Investigations into the Effect of Constitution on the Malleability of Steel at High Temperatures."

FRIEND, J. NEWTON, and B. L. GRIFFIN—"The Protection of Iron with Paint against Sub-Aqueous Corrosion."

MACNAIR, P. M.—"Slag Metal Reactions."

MERRILLS, F. S.—"Studies in the Fatigue of Metals."

PARKIN, A. M.—"The Effect of Heat Treatment and of Variable Carbon Content on a Tungsten Magnet Steel of Fixed Tungsten Composition."

WILLIAMS, W. E.—"The Application of X-Ray Analysis to the Study of Hardened Steel."

WOODVINE, J. G. R.—"The Behaviour of Case-Hardened Parts under Fatigue Stresses."

MINING AND METALLURGICAL CONGRESS.

In addition to these two statutory meetings, the Institute took part, in its corporate capacity, in the promotion of the Empire Mining and Metallurgical Congress, which was held at the British Empire Exhibition, Wembley, on June 3, 4, 5, and 6. The convening bodies were: The Institution of Mining and Metallurgy; The Institution of Mining Engineers; The Institution of Petroleum Technologists; The Mining Association of Great Britain; The Iron and Steel Institute; The Institute of Metals; and The National Federation of Iron and Steel Manufacturers.

His Royal Highness the Prince of Wales graciously consented to become Honorary President of the Congress. The President of the Congress was Viscount Long of Wraxall, whose great services were universally acknowledged. By his death a few months later the country and Empire sustained a grievous loss.

The Congress was divided into four sections :

SECTION A.—Mining. *Presidents*: Mr. Humphrey M. Morgans; Sir John Cadman, K.C.M.G.

SECTION B.—Petroleum. *President*: Mr. Herbert Barringer.

SECTION C.—Metallurgy of Iron and Steel. *President*: Sir William Ellis, G.B.E., D.Eng., and

SECTION D.—Non-Ferrous Metallurgy. *President*: Professor T. Turner, M.Sc.

The following papers were presented and discussed in Section C :

CAMERON, C. S.—“The Iron and Steel Industry in Canada.”

CLEMENTS, F.—“Modern British Blast-Furnaces.”

HADFIELD, Sir R. A., Bart.—“The Development of Alloy Steels.”

HADFIELD, Sir R. A., Bart.—“Works Problems and Methods in Fuel Economy.”

HARBORD, F. W., and E. F. LAW—“British Iron and Steel Industry.”

HATFIELD, W. H.—“Modern Developments in Metallurgy of Special Steels.”

HEBDEN, G.—“A Comparative Survey of Coke-Oven Practice in Various Countries.”

LARKE, Sir W. J., and M. S. BIRKETT—“Some Economic Considerations affecting the Iron and Steel Industry.”

PEARCE, J. G.—“The British Cast Iron Research Association: Its Present Work and Future Development.”

SANTER, E. H.—“Railway Steels.”

TUCKWELL, H. M. S.—“The Iron and Steel Industry in India: Its Rise, Present Position, and Future Prospects of Development.”

These papers and discussions thereon have since been reprinted as Part IV. of the Proceedings, and the volume is on sale separately at 10s. 6d. The price of the whole five bound parts, which comprise the General Proceedings and those in the Mining, Petroleum, and Non-Ferrous Sections, as well as the Iron and Steel Section, is £2 2s.

Amongst the social functions in connection with this Congress was a Reception at the Imperial College of Science and Technology, and an official Banquet which was held at the Guildhall on Thursday, June 5, and at which Prince Arthur of Connaught was the principal guest.

BESSEMER MEDAL.

The Bessemer Gold Medal for the year 1924 was awarded by the Council to Professor Albert Sauveur of Harvard University, Cambridge, Mass., for his eminent researches in the microstructure and metallurgy of iron and steel.

ANDREW CARNEGIE RESEARCH SCHOLARSHIPS.

Grants were made during the year by the Council, on the recommendation of the Carnegie Scholarship Committee, to the following candidates :

- C. H. ADAMSON (Sheffield) and G. S. BELL (Lincoln), £100 jointly, to carry out an investigation on transverse test-bars of cast iron of various mixtures, and to determine the relation between the strength, properties, and chemical composition.
- L. ARCHISON (Birmingham), £100, to carry out a research on the critical quenching velocity of steel and the influence of composition upon it.
- C. E. PEARSON (Newcastle-on-Tyne), £75, to investigate the growth of commercial grey cast iron, with special reference to composition, grain-size, and casting thickness.
- E. R. TAYLOR (Birmingham), £75, to ascertain the relationship between sulphur and other ingredients of white iron in connection with the production of white-heart malleable castings.

It was also recommended that a further grant of £50 be made to O. W. Ellis (Toronto University) (who had received a grant of £100 in 1922), to enable him to install certain apparatus for continuing his research work already reported on.

PUBLICATIONS.

The publications of the Institute during 1924 comprised two volumes of the Journal, aggregating nearly 1300 pages, a volume of Carnegie Scholarship Memoirs, containing over 300 pages, and the usual List of Members, Charter, and Byelaws (170 pages). In connection with the Empire Mining and Metallurgical Congress, to which reference has already been made, a volume of proceedings in Section C (Metallurgy of Iron and Steel), containing over 300 pages, has likewise been published.

LIBRARY.

The growing need of housing the very considerable collection of text-books, bound periodicals, &c., has necessitated the carrying out of a process of reconstruction by which it is hoped that the volumes may become more readily and more conveniently accessible to members desirous of using the Library. The Reading Room has been entirely refitted with shelving, and can now accommodate 2500 text-books and periodicals out of the 12,000 volumes comprised in the collection. The Council are pleased to note the increased use being made of the Library, and the fact that the technical and other inquiries dealt with either directly or by post have increased considerably. The expenses to be met for the purchase of books and periodicals, binding and administration, are unavoidably heavy, and the Council would therefore warmly

welcome donations to the Library for the purpose of purchasing additional volumes, and the presentation of new books dealing with the technology of the Iron, Steel, and Allied Industries.

The additions made to the collection of books during the year include the following donations from authors, publishers, and others, to whom the Council take this opportunity of extending their thanks : "The Manufacture of Electric Steel," by F. T. Sisco ; "Calcul du lit de fusion des hauts-fourneaux," by M. A. Pavloff ; "Pulverised Fuel, Colloidal Fuel, Fuel Economy, and Smokeless Combustion," by L. C. Harvey ; "Fuel Economy in Steam Plants," by A. Grounds ; "Fuel," by G. W. Andrew ; "Ferrous Metals," by M. S. Birkett ; "Non-Ferrous Metals," by N. M. Penzer ; "Materialproving," by B. A. Kjerrman ; "The Specific Heat of Gases," by J. R. Partington and W. G. Shilling ; "Theoretical Metallurgy," by R. S. Dean ; "The Metallurgy of Iron," Part I., by M. A. Pavloff ; "Taschenbuch für Berg- und Hüttenleute," by F. Kögler ; "The Planning, Erection, and Operation of Modern Open-Hearth Steelworks," by H. Hermanns ; "Les Œuvres Sociales des Industries Métallurgiques," by R. Pinot ; "Combustion in the Gas-Producer and the Blast-Furnace," by A. Korevaar ; "Practical Microscopical Metallography," by R. H. Greaves and H. Wrighton ; "William Kelly : A True History of the So-Called Bessemer Process," by J. N. Boucher ; "The Corrosion of Metals," by U. R. Evans ; "Iron and Steel in the Industrial Revolution," by T. S. Ashton ; Documents and Papers collected by the late Dr. Percy in preparation for a second edition of the "Iron and Steel" volume of his work on "Metallurgy," arranged and indexed by H. G. Graves ; "Economics of Iron and Steel," 2nd edition, by H. J. Skelton ; "España ante el Hemisferio de Occidente," Vol. I., by J. de Lazúrtegui ; "Geschichte des Eisens," by O. Johannsen ; "Physics in Industry," Vols. I. and II. ; "Grundbegriffe der Mechanischen Technologie der Metalle," by G. Sachs.

Among the books that have been purchased are : "X-Rays and Crystal Structure," 4th edition, by Sir W. H. Bragg and W. L. Bragg ; "The Microscopic Analysis of Metals," by F. Osmond and J. E. Stead, 3rd edition, revised by L. P. Sidney ; "Petroleum Resources of the World," by V. R. Garfias ; "Mechanical Testing," Vol. II., by R. G. Batson and J. H. Hyde ; "Coke and its Uses," by E. W. L. Nicol ; "The Utilisation of Low Grade and Waste Fuel," by W. F. Goodrich ; "Low-Temperature Carbonisation," by S. N. Wellington and W. R. Cooper ; "A Text-Book of Ore Dressing," by S. J. Truscott ; "Modern Electro-Plating," by W. E. Hughes ; "Dictionary of

Applied Chemistry," Vol. V., by Sir Edward Thorpe; "The Chemistry and Physics of Clays and other Ceramic Materials," by A. B. Searle; "Low-Temperature Carbonisation," by C. H. Lander and R. F. McKay; "The Mineral Deposits of South America," by B. L. Miller and J. T. Singewald; "The Electric Furnace for Iron and Steel," by A. Stansfield; "The West of England Tin Mining," by W. S. Lewis; "South Wales Coals: their Analyses, Chemistry, and Geology," by L. J. Davies and D. O. Davies; "Bibliography of the Corrosion of Metals and its Prevention," by N. Van Patten; "The Chemical Resistance of Engineering Materials," by M. L. Hamlin and F. M. Turner, jun.; "Die Konstruktionsstähle und ihre Wärmebehandlung," by R. Schäfer; "Metallographie," Vol. II., Part II., No. 6, Vol. III., Sections 1 and 2, by W. Guertler.

APPOINTMENT OF REPRESENTATIVES.

The President continues to represent the Institute on the General Committee of the Royal Society for administering Government Grants for Scientific Investigations. Sir Robert Hadfield, Bart., and Mr. F. W. Harbord, C.B.E., represent the Institute on the Board of the National Physical Laboratory, and Sir Hugh Bell, Bart., represents the Institute on the Board of Governors of the Imperial College of Science and Technology. The Institute representatives on the British Engineering Standards Association are Dr. A. Cooper, Mr. M. Mannaberg, and Mr. B. Talbot. On the Sub-Committee of that Association, for the Standardisation of Galvanised Sheets, Mr. C. Dorman continues to serve; while Mr. H. J. Yates and Dr. W. H. Hatfield are the representatives on the Sub-Committee for Cast Iron, working under the direction of the Sectional Aircraft Committee; Mr. H. B. Toy represents the Institute on the Sectional Committee on Cast Iron; Mr. J. H. S. Dickenson is the representative on the Technical Committee of Motor Industries; and Mr. F. W. Harbord, C.B.E., on the Sectional Committee for Chemical Engineering. Mr. F. Clements is the Institute representative on the Institution of Civil Engineers' Panel D on Gas-Producer Trials. Professor T. Turner acts as the Delegate of the Institute to the British Cast Iron Research Association. Mr. Harbord is the representative on the British Refractories Research Association, and also on the Alloys of Iron Research Committee. The Institute is represented by Dr. A. Cooper, Mr. M. Mannaberg, Mr. G. Hatton, C.B.E., and Mr. B. Talbot on the Committee on the Improvement and Development of Basic Slag, formed

by the Ministry of Agriculture and Fisheries. Professor T. Turner represents the Institute on the Grey and Malleable Iron Research Committee of the Department of Scientific and Industrial Research ; on the Technical Committee of Lloyd's Register of British and Foreign Shipping the Institute is represented by Lord Invernairn and Mr. W. Simons. Sir Robert Hadfield, Bart., represents the Institute on the British Association Fuel Economy Committee, on the Court of Sheffield University, and on the Home Committee for the University of Hong Kong ; while on the Court of the University of Liverpool the Institute is represented by Sir W. Peter Rylands. Mr. F. W. Harbord acts as representative on the Advisory Board of the Royal School of Mines, and, with Sir Robert Hadfield, Bart., represents the Institute on the Federal Council for Pure and Applied Chemistry.

CHANGES ON THE COUNCIL.

Sir William Ellis, G.B.E., D.Eng., was at the Annual Meeting in May elected President of the Institute, Colonel Sir W. Charles Wright, K.B.E., C.B., being elected a Vice-President to fill the vacancy thus created, and the Hon. R. D. Kitson, D.S.O., M.C., being elected a Member of Council in his place.

The statutory year just concluded is the first during which the newly altered Byelaw 10, limiting to one year the period during which a President should hold office, has been in operation, and the Council in accordance therewith unanimously nominated Sir Frederick Mills, Bart., Vice-President, to succeed Sir William Ellis as President. Mr. W. H. Hewlett, Mr. C. J. Bagley, and Mr. E. Steer, Vice-Presidents, have been elected Honorary Vice-Presidents ; the vacancies thus caused in the list of Vice-Presidents having been filled by the election of Mr. W. R. Lysaght, C.B.E., Mr. F. W. Harbord, C.B.E., and Mr. B. Talbot as Vice-Presidents respectively. Professor H. Le Chatelier, F.R.S., has also been elected an Honorary Vice-President, and Mr. F. W. Gilbertson has resigned his seat on the Council. The vacancies on the Council which have thus occurred have been filled by the election of Professor C. H. Desch, F.R.S. ; Mr. V. B. Stewart, C.B.E. ; Professor T. Turner, F.I.C. ; Mr. W. Simons ; and Mr. A. Dreux.

The names of the following Vice-Presidents and Members of Council were announced at the Autumn Meeting as being due to retire (in accordance with Byelaw 10) at the Annual Meeting in 1925 :

Vice-Presidents—Mr. A. Lamberton ; Sir W. Charles Wright, K.B.E. ; Mr. M. Mannaberg.

Members of Council—Mr. C. Markham ; Mr. G. Hatton ; Mr. B. Talbot ; Mr. H. Brearley ; Professor H. Louis. Mr. Talbot having in the meantime been elected a Vice-President, the vacancy thus arising has been filled by the election of Mr. A. Dreux, who is now due to retire in rotation in place of Mr. Talbot. No other members having been nominated up to one month previous to the meeting, in response to the announcement made at the Autumn Meeting, the retiring members, subject to the change specified, are presented for re-election.

THE IRON AND STEEL INSTITUTE.

BALANCE SHEET, DECEMBER 31, 1924.

STATEMENT OF ACCOUNTS.

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LIABILITIES.

Sundry Creditors:—

Journal Printing and Publishing	£549 6 5
Journal Postage	54 18 11
Library Books and Binding	11 11 3
Office Rent, &c.	265 6 11
Office Furniture	98 2 6
Stationery, Printing, and Postage	32 9 4

Entrance Fees and Subscriptions in advance

Journal Sales, Amount received in advance	£1,011 15 4
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Life Compositions Fund:—

Fees received during year	81 12 9
Add Transfer from Institute Capital Account in respect of	22 13 0
Composition Fees received in previous years	2,942 19 3

Carnegie Scholarship Fund:—

Sundry Creditors—	2,990 4 3
Grants due 1924	£225 0 0
Amount due to Institute's General Fund	47 13 6

Amount of Fund

Add Accumulated Surplus Income:—	£272 13 6
As at 1st January 1924	21,241 5 6
Add Excess of Income over Expenditure to 31st December 1924	239 3 6

Special Purposes Fund:—

Capital Account, representing subscriptions received 1919-20 invested <i>per contra</i>	9,451 0 0
Amount due to Iron and Steel Institute	11 8 0
Income and Expenditure Account:—	£900 6 3
Balance at 1st January 1924	87 13 4
Deduct Excess of Expenditure over Income for the year ended 31st December 1924	812 12 11

Iron and Steel Institute Capital Account:—

As per last Balance Sheet	£18,282 19 3
Add Excess of Income over Expenditure for the year	499 12 11

Deduct Transfer to Life Composition Fund of amount of

Composition Fees of previous years invested	18,782 12 2
	2,942 19 3

15,839 12 11

£55,286 2 2

ASSETS.

Sundry Debtors:—

Entrance Fees and Subscriptions in arrear, since received	£164 17 0
Journal Sales, since received	10 18 9
Interest on Investments	232 13 9
Amount due from Carnegie Scholarship Fund	47 13 6
Amount due from Special Purposes Fund	11 8 0
Telephone Deposit	1 10 0
Miscellaneous	7 6 9

£476 12 9

45 8 4

Journal Paper—In Stock

Investments, at cost, as per Schedules:—	...
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General Fund	15,562 12 5
Life Compositions Fund	2,864 4 3

18,426 16 8

Cash at Bank and in Hand:—

General Account	£10 15 4
Deposit Account	504 0 0
Life Compositions Fund	126 0 0
Secretary's Account	350 4 2
Cash in Office	6 1 0

997 0 0

Carnegie Scholarship Fund:—

Investments at cost, as per Schedule	£22,146 7 10
Interest on Investments accrued due at 31st December 1924, since received	377 14 3
Cash at Bank on Deposit Account	2,541 0 11

25,065 3 0

Special Purposes Fund:—

£12,242 19s. 3d. 4. per cent. Funding Stock, 1900-90	£9,512 7 5
Cash at Bank:—	...
Current Account	7 8 9
Deposit Account	755 4 9

762 13 6

10,275 0 11

£55,286 2 2

STATEMENT OF ACCOUNTS.

GENERAL FUND.
ACCOUNT OF INCOME AND EXPENDITURE FOR THE YEAR ENDED DECEMBER 31, 1924.

INCOME.			EXPENDITURE.		
To Entrance Fees	...	...	By Salaries (including Overtime)	...	£3251 12 10
" Annual Subscriptions:—	...	...	" Office Rent, Cleaning, &c...	...	1065 9 5
Members	...	...	" Library Books and Binding	...	163 3 2
Associates	...	...	" Office Furniture	...	134 5 3
" Journal Sales	...	...	" Autumn Meeting	...	294 12 9
" Index Sales	...	...	" Annual Meeting	...	104 19 6
" Interest on Investments, Less Tax:—	...	...	" Journal Publishing Expenses:—	...	...
General Fund	...	...	Printing, &c.	...	£1632 8 8
Income Tax recovered to April 5, 1924	...	...	Abstracts	...	98 11 10
Life Compositions Fund...	...	...	Translations	...	15 15 6
Income Tax recovered to April 5, 1924	...	...	Postages	...	104 0 5
" Bessener Medal Fund:—	...	...	" Stationery and Printing (including copies of Papers)...	...	1850 16 5
Interest on Investments, Less Tax	...	...	" Postage and Receipt Stamps	...	341 8 4
Income Tax recovered to April 5, 1924	...	...	" Travelling Expenses	...	120 6 11
" Interest on Deposit	...	...	" Insurance	...	22 16 3
" Sale of Waste-paper, &c.	...	...	" Telephone Rental and Calls	...	27 9 2
" Surplus on Italian Meeting Fund, 1923	...	...	" Auditor's Fees	...	23 14 10
" Sundry Receipts	...	...	" Bessener Medal	...	31 10 0
			" Compassionate Allowance	...	14 18 0
			" Office Disbursements and Sundry Payments	...	60 0 0
				...	71 9 11
				...	7588 12 9
				...	499 12 11
				...	£8068 5 8
				...	£8068 5 8

" Excess of Income over Expenditure carried to Balance Sheet

ACCOUNT OF INCOME AND EXPENDITURE FOR THE YEAR ENDED DECEMBER 31, 1924.

To Interest on Investments:—

£2250 Newcastle-upon-Tyne Electric Supply 4½ per cent. Consolidated First Mortgage Debenture Stock	£78 9 4
£7925 London & North Eastern Railway 4 per cent. Debenture Stock...	245 13 6
£1312 London & North Eastern Railway 4 per cent. 1st Guaranteed Stock	40 13 10
£8760 London & North Eastern Railway 3 per cent. Debenture Stock...	203 8 10
£2000 London Midland & Scottish Railway 4 per cent. Debenture Stock	62 0 0
£1500 Great Western Railway 4 per cent. Debenture Stock	46 10 0
£2560 4½ India 3 per cent. Stock	76 16 0
£2300 India 3½ per cent. Stock	80 10 0
£1000 5 per cent. War Stock, 1939-47	38 11 0
Interest on Deposit	...
" Income Tax recovered to 5th April 1924	...

Interest on Deposit	...	...	£872 12 6
Income Tax recovered to 5th April 1924	...	...	54 9 0
	...	...	215 15 8

£1142 17 2

By Scholarship Grants	£425
Less Balance of 1922 and 1923 Grants lapsed...	125

" Printing Memorls ..	...	...	...	£300 0 7
" Postage of Memorls ..	...	...	...	456 19 7
" Salaries ..	...	...	...	43 14 1
				104 0 0
				£903 13 8
" Excess of Income over Expenditure carried to Balance Sheet				239 3 6

“ Excess of Income over Expenditure carried to Balance Sheet

£1142 17 2

SPECIAL PURPOSES FUND.

ACCOUNT OF INCOME AND EXPENDITURE FOR THE YEAR ENDED DECEMBER 31, 1924.

To Interest on Funding Stock

“ Standing Stock	£434	12	6
“ Interest on Deposit	11	10	4
“ Income Tax recovered	55	1	10
	501	4	8
“ Excess of Expenditure over Income carried to Balance Sheet	87	13	4
	£588	18	0

Excess of Expenditure over Income carried to Balance Sheet

£588 18 0

By Grants:—

Empire Mining and Metallurgical Congress	...	£250	0	0
Alloys Research Committee	...	250	0	0
Ramsay Memorial Laboratory	...	52	10	0
British Refractories Research Association	...	25	0	0
Expenses of Technical Committee	...	...	...	...

$$\begin{array}{r} 577\ 10\ 0 \\ 11\ 8\ 0 \\ \hline 588\ 18\ 0 \end{array}$$

Iron and Steel Institute.

PRESIDENTIAL ADDRESS.

BY SIR FREDERICK MILLS, Bt., D.L., M.INST.C.E., M.I.MECH.E.

I HAVE chosen for the subject of my address that of certain aspects of the economics of the heavy iron and steel industry, feeling that the conditions ruling here at present, as for some years past, call for investigation as to their cause, and some attempt to suggest lines of thought for your consideration.

1. Sir William Larke and Mr. Birkett jointly presented a paper on this subject to the Empire Mining and Metallurgical Congress at Wembley last year, and in February this year Sir William Larke presented to the Balfour Committee a comprehensive written statement of the problems that beset the industry, both of which are alike admirable. By referring you to these documents I am able to refrain from going over the ground they cover; but I am still left with one or two aspects of my subject which are to me not only of great interest, but are, apparently, of extreme importance.

2. The discussion of the subject necessarily involves the consideration of such matters as trade and labour, and I am well aware that the by-laws in our Charter expressly enjoin that there shall be no such discussions at our meetings; Clause II. reads: "Excluding all questions connected with wages and trade regulations."

3. I feel, however, that some of your Presidents—being human like you and me—must have transgressed against that by-law, and, looking back, I find by way of example, twenty-two years ago, a distinguished personality, Mr. Andrew Carnegie, in his address to you, buried himself deeply in the subject.

4. Some of you will remember his address; not only did he discuss sliding scales and wages, remuneration of managers and their assistants, but he also discussed the division of profits. True, a little later in his speech he is compelled to call attention to the disasters of some of his neighbours in the United States, notably the Pennsylvania Steel Company, which had evidently recently been in the hands of a Receiver, and of the Lake Superior Iron

Ore Company, whose Preferred Shares had been quoted at 80 dollars shortly before, and were on that day $15\frac{1}{2}$ dollars, while the Common Stock had sold the year previous at 36 dollars and were that day to be bought at 4 dollars, and so forth ; a tale of financial woe that can be matched here to-day—truly, I am encouraged by my precedent to discuss our own economics.

5. The iron and steel industry of this country is one of the most important of all our industries. Richard Cobden called it "the Father of all the Industries" ; working to capacity it gives direct employment to 300,000 persons, and indirectly in engineering and shipbuilding to 1,000,000. I at once ask this question—Are we entitled as a nation to continue in it, or must we let it go ?

6. What has been, may well be again. Historically, we have a proud record ; as in other countries, until the days of James Watt, who taught the world how to harness steam, our iron and steel production was not of great quantity, although of the very best in quality, but at the very beginning of what is known as the Industrial Era we at once sprang into the first place as producers of iron. To those who are concerned to read about the audacious courage and the trials and difficulties of our predecessors, I recommend the excellent work of Professor T. S. Ashton, M.A., of Manchester—"Iron and Steel in the Industrial Revolution"—recently published. I would also refer you to the invaluable address on "Metallurgy, and Its Influence on Modern Progress," delivered by our eminent Past-President, Sir Robert Hadfield, at Oxford in January this year.

7. So we continued until the adoption of Bessemer's invention by the United States, whereby in a very few years the colossal development of that great country began, and at the same time and by the same means—graciously acknowledged—they wiped off their National Debt. In recent years they have outstripped us in point of tonnage, as indeed did Germany following the introduction of Bismarck's Tariff Laws in 1878. It seems to be a matter of reproach in the minds of some latter-day controversialists that Great Britain now takes third or even fourth place in her output of iron and steel ; to me that signifies little ; the real test surely is—is our industry progressing, is it prosperous (in the widest sense of that word), and is it adequate to the needs of the nation and of the Empire ?

8. We cannot, I fear, say that we have progressed steadily or prosperously, for if you consult the statistics recently prepared by the National Federation of Iron and Steel Manufacturers, you will find no marked progress, merely ups and downs. The pig iron output last year was 30 per cent. below that of 1913, and whilst the output of steel was approximately the same, there was imported no less a quantity of iron and steel than two and a half million tons, which, had it been produced here, would have made a good showing; the total steel output would have been approximately eleven million tons, giving us second place among the nations; 100,000 more men would have had employment instead of being in receipt of the deadly "dole," and in addition the price of the home product would not have been regulated by the "give-away" prices of the foreign steel.

9. We at home are faced with two plain facts :

- (1) The cost has, since pre-war days, increased some 50/60 per cent.
- (2) Selling prices have increased by only 30 to 40 per cent.; in consequence the scant margin of pre-war profit has disappeared, and the industry has become unprofitable.

10. What can we do? But, first, what have we done? During the war much patchwork improvement was effected, mainly at the instance of the Government. I have recently had the opportunity of inspecting a large number of plants in this country where these improvements have been made, and being fairly familiar by personal experience with corresponding plants on the Continent and in the States, I have no hesitation in saying that they are equal, if not superior, to them, and they reflect the greatest possible credit on the skill of our home engineers, and those directing them. Unfortunately, no co-ordination was attempted, nor could there have been; clearly the urge of the moment was the guiding factor. A great deal of the improvement was, however, of permanent value, notably the score of new blast-furnaces, projected and commenced, but none completed during the war; a great deal of open-hearth and rolling-mill plant was completed, but unfortunately many of these schemes were left in the air by the Government in their natural and praiseworthy haste to bring war expenditure to a close.

11. This state of affairs is very unfortunate, especially as few British firms have now the funds available to complete their lay-out on the modern lines they intended. The men controlling affairs are only too well aware of the vast sums taken out of the industry by the penal taxation of the war and immediate post-war period, instead of being utilised as they should have been, and could easily have been, in finishing off that which had been well begun. And, again, there was a great lack of co-ordination and even ordinary justice in the matter of writing-off allowances, so much so that it is possible to sum up and say that those firms that were the most willing to help by making themselves responsible for a crushing burden of funded and unfunded debts have come out worst. That may be "the way of the world," but it is unfortunate for the industry. The Government of the day might reasonably do something to repair the damage done by their predecessors by guaranteeing the provision of new cheap capital to complete these extensions.

12. For twenty-five years before the war we here were subject to a constant invasion of surplus iron and steel from any country in need of an outlet for it; in some years that importation amounted to as much as 25 per cent. of the home product, and I need hardly tell my audience that the price of so large an import naturally regulated the prices of the corresponding home product—in fact, it is well known that the margin of profit was so meagre that such improvement in plant as was made before the war required prolonged deliberation, and in all cases the necessary funds were grudgingly provided. Admittedly our industry was not at its best when the sudden catastrophe of 1914 called upon it to provide the sinews of war for two great nations; it is not surprising that we were unable to meet the strain, and consequently some portion of our task was undertaken by our cousins across the Atlantic, to whom we, as a nation, owe our cordial thanks.

13. No responsible Government nor body of public opinion dare advocate running a similar risk in future; already serious alarm is being felt both by the Government and by the public, and presumably "something will be done"—what that something should be is of a character quite unsuitable for discussion here; clearly the particular competition to which the iron and steel industries are here subject at the present time, and have been for many

years past, is in many respects unfair, as Sir William Larke in his evidence to the Balfour Committee has testified. It may require special legislation for a few years, but whatever governmental action be taken it is obvious that those who control the industry must be prepared to co-operate and to show that they know how the industry can be made efficient and adequate.

14. Has our hand lost its cunning? I venture to think it has not. When you contemplate the development that has taken place in the last ten years in the matter of fuel economy, the utilisation of by-products (until the production of steel has itself almost become a by-product of coal), the improvement in quality, of the methods of physical testing and of chemical determination, of engineering design and construction, you must feel reassured that we still have in our midst first-class brains.

15. On the other hand, unfortunately, we have to deplore the fact that our costs in regard to two items—coal and labour—have increased enormously and are altogether too high; coal and labour are almost identical terms, and I desire to draw your attention to them.

16. The price of metallurgical coal has advanced some 80 per cent. since pre-war days; for that calamity the metallurgical community, as such, is not responsible; but had we not in pre-war days set about the subject of fuel economy and continued in it since, iron and steel making on a large scale in this country might well have already become a thing of the past. It is not our province to produce cheaper coal, but it is competent for us to call for cheaper coal if the British iron and steel industry, and those others dependent upon it, are to live.

17. The other outstanding item of cost is that of labour—and here again steel and labour are almost identical terms—and at the outset I want to make it clear there can be no quarrel with the average earnings of the men employed in the iron and steel trades, although the disparity in earnings of the highest and lowest seems to call for adjustment. Further, I wish to pay a tribute to both sides of the Wages Regulation Boards, which have clearly the best record for forty years, in the matter of avoiding strikes and lock-outs, of all the greater industries in the country. It is not that I am calling your attention to earnings, but rather to the cost per ton for labour.

18. What, then, is wrong? I am of opinion that the subject of labour has not had that amount of consideration and understanding that is necessary. How many men in the street would at once agree that the percentage of "ultimate" labour in the cost of a ton of steel amounts to at least $92\frac{1}{2}$ per cent.? Very few. Most of them would guess about 50 per cent.; indeed, one constantly reads the expression of publicists, both parliamentary and otherwise, who put it no higher.

19. I have been interested in this subject for many years. A few years ago, with the assistance of Mr. Thomas, the head of the Cost Department at Ebbw Vale, we worked it out "in real herrings," as Sir James Barrie would say; we started with a ton of coal—where we not unnaturally found the ultimate labour cost is quite 90 per cent.—obviously here, the great bulk of the cost must consist of labour, and then we worked out every item of every stage of conversion to the final ton of steel.

20. It is an interesting study, but I do not wish to burden you with figures (I give you the result of our investigations in the Appendix). But let us consider the *rationale* of the subject; the coal, iron ore, and the limestone are lying in the earth as a Benevolent Creation left them; how do they get themselves into a ton of steel? First, let us take the case of coal; the details, which are typical of any cost, are given on the first page of the Appendix; there you will find, worked out in percentages, every detail of an exact cost at a particular group of collieries some months ago; the direct labour is over 50 per cent.—the 50 per cent. of the theoretical economist of whom I spoke—but I shall have no difficulty in bringing practical men to the view that direct labour by no means exhausts the tale; no fewer than six other items of the cost are 100 per cent. labour, the remainder have been ascertained by reference to the actual pay-sheets.

There was an immense amount of labour involved in making this analysis, as also the continuation analysis in the second page; every item was checked and cross-checked. You may take them as absolute so far as this particular group is concerned, because even where the labour cost is not obtainable from the records of the composite company owning the collieries, they are of so local a character as to be readily obtained. Moreover, the calculations have been checked by analysing the costs at other collieries and

at other periods, as variable as pre-war, in 1920, and now, and the percentages of labour are found to be constant.

The percentages will vary elsewhere if materials are purchased or where railway carriage is involved, because an outside profit and loss account is involved.

21. Royalty is rent, from which there is no escape, even if royalties be transferred from the individual to the State, with or without compensation. I am not concerned to discuss the problem here; my inquiry is as to the causes of increased cost, and as the charge for royalty on coal has increased only since pre-war days by the gradual change from old leases to newer ones—that is to say, from 6d. to 6¼d. a ton over the United Kingdom—the item has little effect; it is curious, perhaps, to observe that this much discussed but little understood charge contains by actual ascertainment 30 per cent. labour.

22. I say the discovery of the exact ultimate percentage of labour is an interesting study. I find all the commodities I have examined contain from 90 to 95 per cent. labour cost, and I am accordingly inclined to the belief that all commodities are alike in this respect, such dissimilar things as a ship, a postage stamp, a railway rate, a book, a loaf of bread, a telephone call, a house, 1000 feet of gas, a newspaper, and so on. It is quite conceivable others in other industries have already made the same discovery; to me it is a recent one, and only by accepting it can I square cause and effect.

If the labour cost is over 90 per cent., of what does the balance consist? We have investigated that, and find that if everything required to make a ton of steel were concentrated under the same control and no profit be charged until after the total and final cost be ascertained, then the balance is once more nearly all ultimately labour; indeed, our inquiry leads us to suppose that the 92½ per cent. arrived at is limited only to that figure by fear of a charge of overstatement, and where no profit on stores, outside service, and the like is involved the real labour cost is nearer 97½ per cent.

The inference therefore is, that it pays any community to employ its population to the fullest extent, because it thereby becomes a full-time consumer at the same moment it is a full-time producer.

Let me repeat, the coal and the iron ore lie as nature left them in the ground and have cost man nothing ; man digs them up, and burns the first to smelt the second ; he manipulates the crude substance into the required final product—all labour up to a point, and that point lies between 90 and $97\frac{1}{2}$ per cent.

23. Then what ? If on examination for yourselves you confirm and accept my estimate that a ton of steel consists of over 90 per cent. labour, you will appreciate that if we are to improve our costs we must so order our affairs both public and private that we can get a better output for the labour now employed, because you will remember that I do not complain of the average earnings, but of the cost of labour per ton. If we can do this, if we can get more tons, we can get them cheaper, we can sell more tons and therefore increase employment.

I stress the view that a ton of steel consists of 90 to 95 per cent. labour, because I want works managers to cease to regard a ton of steel as a ton of steel, and to regard it rather as nine-tenths of a ton of labour. Put it another way—if that 5-ton ingot on its casting car could have been made with half the number of men, or if two 5-ton ingots could have been produced by the same number of men, they would have cost approximately half as much. It can be done, and there would be no hardship to anyone, only benefit and increased employment, because we could make more tons and sell more tons in competition with the world, and thereby employ more men.

The leaders of our men must tackle the subject from this point of view, and co-operate with the managers ; every furnace, every machine, must be allowed to work to full capacity, and until they can persuade their continental brethren to come up to our conditions they must approximate our hours of work and wages to theirs, or produce proportionately more per unit of labour, if our industry is to live. Some of the fancy earnings, such as the £20 to £25 a week—clearly unearned increment—paid to the thirty first-hand melters in a 10-furnace shop must be amended if the product has to be sold against the product of a similar shop abroad where the corresponding wage is £2 to £3 a week.

24. Let me return to coal : it is admittedly the foundation of our industry. The cost for coal per ton of steel varies as to the iron contents of the ore from which steel is made ; in Great Britain

it varies from one-fourth to one-half of the total cost of the steel made. We see, therefore, how important it is that the industry should be provided with coal at a lower price than at present.

It is not the metallurgist's job; we can only call for it. I will content myself by saying if it is not forthcoming at a price comparable with the price in Europe or the States, England must cease, for a time at least, to expect to support a manufacturing population. I decline, however, to think that the call will not be answered—it is too obvious that it must be.

25. On our part there is still much room for improvement in our use of coal; great strides have from necessity been made in recent years, but the subject of fuel economy in our ironworks, and particularly in our steelworks, will afford further scope for study and research. It is not inconceivable that the coke-ovens should be the only consumer of all the coal required to make a ton of steel.

26. Are we quite sure we were correct in our policy of rejecting, for the most part, the use of large gas-engines using coke-oven and blast-furnace gases?—the discovery of B. H. Thwaite, and first employed at Wishaw in 1896. The process is nearly universal on the Continent; there are works there making 40,000 to 50,000 tons of steel a month which have no other source of power, except for emergency, and I am convinced this subject deserves further consideration. Something has been done by some firms. I saw recently one works where gas-engines are largely employed, and others where they are partially employed, but in most of our establishments they are entirely absent.

27. There are plants in this country where the coke-ovens and blast-furnaces are excellent, and where the cost of conversion from coal to pig iron is second to none, but in those cases the benefit is lost in the subsequent processes. There are plants where the reverse is equally true. It will be in the best interests of the industry if means can be found to reconstruct a number of the plants in agreed areas and bring them as near perfection as possible.

28. It will be of still further benefit if our proprietors can amalgamate their interests, and arrange for the segregation of orders and concentrate them into those areas and those works most suitable for their production; our present practice—the

survival of former years—whereby a great variety of shapes is rolled in the same works is wasteful ; specialisation is the order of the day—we must adopt it.

Can we not go even further ? Is it beyond the wit of those who control our hundred and one iron and steel works to devise means for the physical amalgamation of those plants which are geographically suited for the purpose ? The public may be afraid of a Trust—they need not be ; there are real Trusts all around them, unobservable, or at least unremarked. But apart from that, should such grouping result in greater efficiency, I venture to suggest grouping, combined with prosperity and progress, is of greater use to a country than insane competition and stagnation.

29. The immediate outlook for our industry is indeed obscure. It has been well said that the maker of iron and steel is either prince or pauper—my forty years' experience tells me he is never of the middle classes ! The times are out of joint ; after every great international upheaval in the past the iron trade has suffered, the greater the upheaval the greater the suffering, but always we settle down on a new level, and by and by, when continental exchanges cease to be expressed in such variable figures, we will the better understand just where we stand.

Professor Ashton has related the difficulties which time and again beset our forbears, and how they overcame them ; shall it be written that we in our day, with the added knowledge of more than a century of study and research, were lacking in that bulldog tenacity of purpose which they possessed, and that we had neither the wit nor the courage to achieve our purpose merely because it was difficult ? I do not think it will.

TABLE I.—Statement showing Allocation of Labour as a Percentage of Through Coal Cost of Production.

	Total Cost (as a Percentage).	Labour Proportion.					
		Direct.		Other British.		Foreign.	
		Percentage.	Labour Cost.	Percentage.	Labour Cost.	Percentage.	Labour Cost.
			Per Cent.		Per Cent.		Per Cent.
Wages	58.16	100	58.16	...	...	100	58.16
Royalty	3.08	...	...	30	0.92	30	0.92
Electricity	5.11	45½	2.30	10	0.51	58½	2.96
Fuel	2.32	80	1.86	12	0.28	98	2.28
Pitwood	8.22	...	...	...	...	80	6.57
Castings	0.53	60	0.32	20	0.11	88	0.47
Bricks	0.13	81	0.11	12	0.02	...	0.13
Stores	5.05	...	...	75	3.79	75	3.73
Stone Dust	0.19	...	0.12	...	...	60	0.12
Betterment Fund	0.49	60	0.49	...	...	100	0.49
Engineering Labour	0.04	100	0.04	...	...	100	0.04
Engineering Material	0.08	50	0.04	40	0.03	90	0.07
Building Stone	0.02	74	0.02	18	...	92	0.02
Pumping	0.05	86	0.04	8	...	94	0.04
Colliers' Train	0.38	...	...	85	0.32	85	0.32
Workmen's Compensation	2.11	100	2.11	...	...	100	2.11
National Insurance—Health	0.50	100	0.50	...	...	100	0.50
National Insurance—Unemployment	1.00	100	1.00	...	...	100	1.00
Traffic	0.29	83	0.24	12	0.03	95	0.27
Wagons	0.02	60	0.01	30	...	90	0.01
Incidentals	6.28	45	2.83	26	1.63	71	4.46
Rates	2.01	...	...	90	1.81	90	1.81
Stables	2.07	20	0.41	65	1.34	85	1.75
Printing and Stationery	0.06	50	0.03	40	0.02	90	0.05
Subsistence	0.21	...	...	95	0.20	95	0.20
House Coal	1.60	100	1.60	...	...	100	1.60
Total	100.00		72.23		11.01		90.14

Iron and Steel Institute.

PROGRESS IN BRITISH ROLLING-MILL PRACTICE.

By T. W. HAND, M.I.MECH.E. (SHEFFIELD).

SOME twenty-four years ago Mr. William Garrett, in reading a paper before this Institute, endeavoured to show, from an American viewpoint, where and to what extent British rolling-mill practice fell short of requirements essential to industrial success. Mr. Garrett's remarks had an important bearing on a subject of absorbing interest at that time, namely, American competition in rolled steel products, and as we are now faced with competition of a still more serious nature, it has occurred to the author that some analysis and discussion of what has been achieved in the period referred to will be of interest at the present time.

Such an analysis necessarily involves consideration of practice in other parts of the world, and as continental mill practice as such corresponds more closely with the best now obtaining in this country, it is proposed, in general, to make comparison with American plants only where intensive development has created the opportunity for what might be termed ideal lay-out.

Admittedly ideal conditions can scarcely be realised in certain steelworks of this country where plant installed by early pioneers has been limited in development through site conditions or financial disability, and remodelling has consequently been permanently handicapped. Further, some temporary advantage as regards low overhead charges can at times be claimed for continuing to work an old plant, which has, in course of time, been written down to a merely nominal capital value. Making due allowance for these important considerations, however, one feels forced to the conclusion that Mr. Garrett's criticisms, whilst perhaps severe, were in the main justified, as no serious attempt appears to have been made during the next fifteen years to keep pace with the class of mill machinery then being installed by rival nations.

It is difficult to find any adequate explanation of this policy, as obviously keen competition can only be met by improved

methods, and possibly more complete recognition of the limitations of human endurance and will might have resulted in fuller development of mechanical means, and created thereby a higher standard of output. This latter is the all-important factor, and if the reasoning now generally accepted in America be admitted, that the investment cost per unit of annual production is approximately equal for all classes of mill machinery, it follows that the largest producing plant is the better investment, as the necessary replacement of arduous manual effort by mechanical devices results in indisputably lower operating cost. This latter aspect will be apparent from inspection of the particulars of operating strength given later in connection with mills of this class.

BLOOMING OR COGGING MILLS.

Reference to Plate I., illustrating the mill lay-out at the Bethlehem Steel Company's Maryland plant at Sparrows Point, will indicate what is expected from a modern American blooming mill. This mill must supply blooms to a Morgan continuous sheet bar and billet mill, also large slabs to a 36 in. \times 110 in. three-high plate mill, and similar material to a universal mill capable of rolling universal plate up to 60 inches wide.

The blooming mill is now producing about 63,000 tons per month, approximately 38,000 tons in the form of blooms for the Morgan mill, and the balance as slabs for the two plate mills. Obviously, such duty calls for mills capable of operating continuously and with the utmost reliability, conditions which are now insisted upon in all modern American works. Fortunately, similar conditions have been imposed on the designers of most of the mills installed in this country during more recent years, and we now have many cogging and slabbing mills, which, if fully supplied with ingots and provided with suitable outlet for product, could establish records in tonnage approaching that above stated. Notable examples of these are given in Table I.

Reverting to Plate I., it will be observed that future extensions incorporate a universal slab mill for relieving the blooming mill of this product when additional plate mills are installed. It should be mentioned, however, that although such mills have been much used in America in the past, the successful develop-

ment of the blooming mill, and that vital essential, the side-guard manipulator, have been largely instrumental in displacing the

TABLE I.—*Some Notable Cogging Mills installed in the United Kingdom, 1915-1925.*

Installation at—	Size of Rolls.	Duty.	Torque at Mill Coupling (Metre-Tons).	Drive.
Bolckow, Vaughan & Co., Ltd.	40" × 9' 0"	General cogging	200 Maximum	Reversing motor
Bolckow, Vaughan & Co., Ltd.	42" × 8' 0"	Cogging for rails and sections	70 Average	40" × 60" two-cylinder reversing steam-en- gines, geared 2 to 1
The United Steel Cos., Ltd. (Temp- leborough plant)	36" × 7' 0"	Cogging for "Morgan" billet mills	230 Maximum	Reversing motor
The Appleby Iron Co., Ltd.	40" × 9' 6"	Slabbing for plate mills	230 Maximum	Reversing motor
Richard Thomas & Co., Ltd. (Red- bourn Works, Scunthorpe)	40" × 9' 0"	General cogging	150 Average	40" × 54" three-cylinder high-pressure reversing steam-engines, geared 2 to 1
The Consett Iron Co., Ltd.	40" × 8' 6"	Slabbing for plate mills	200 Maximum	Reversing motor
Dorman, Long & Co., Ltd. (Red- car Iron & Steel Works)	42" × 10' 0"	Slabbing for plate mills	150 Average	40" × 54" three-cylinder high-pressure reversing steam-engines, geared 2 to 1

universal slab mill, except in such installations as are producing enormous tonnages.

Average practice at the various units of plant illustrated in Plate I. is as follows :

BILLET AND SHEET BAR MILL.

Production.—Up to full capacity of blooming mill.

The entire labour force for the combined blooming, billet, and sheet bar mill comprises 200 men for three eight-hour shifts per day, this number covering every service of the plant, including soaking pits and mechanical and loading forces.

THREE-HIGH PLATE MILL.

Production.

Ten-hour shift	. . .	340 tons.
Month	. . .	12,000 to 15,000 tons.
Maximum slab	. . .	13 in. \times 40 in.
Normal maximum plate	. . .	96 in. \times $\frac{5}{8}$ in. \times 50 ft.
Minimum plate	. . .	51 in. \times 8 gauge from 1300-lb. slab.

The total labour force for this mill comprises 145 men for two ten-hour shifts per day, this number covering mills, shears, all auxiliary services, and loading of product.

UNIVERSAL MILL.

Production.

Ten-hour shift	. . .	425 tons.
Month	. . .	14,000 to 15,000 tons.
Normal maximum plate	. . .	58 $\frac{3}{8}$ in. \times $\frac{1}{4}$ in. \times 30 ft.
Normal minimum plate	. . .	10 in. \times $\frac{1}{4}$ in. \times 130 ft.
Normal maximum slab	. . .	13 in. \times 40 in. \times 12,000 lbs.

For the widest plate rolled, this mill takes an ingot 21 in. \times 60 in. section and 21,000 lbs. weight.

The total labour force for this mill numbers eighty-five men for two ten-hour shifts per day, for all main and auxiliary services.

Fig. 2 illustrates a typical American roll as used on a so-called 36-inch blooming mill. It will be observed that very shallow grooves are used, and the rolls are always worked open, except on the smallest bloom rolled. This practice results in a roll barrel diameter somewhat disproportionate to the dimensions of its driving elements as compared with the old style roll with box holes. For this reason American blooming mill size is defined by pinion centres. The rolls indicated are at present dealing with about 60,000 tons per month, the product being 6 $\frac{1}{2}$ inch square blooms for feeding a Morgan continuous sheet bar mill and a range of slabs for wide strip mills. It will be noted that the ingot is "broken down" on the plain barrelled portion of the roll, thereby eliminating large box holes and incidentally protecting the neck bearings by confining the dispersal of scale to a point nearer the centre of roll. Further, such practice allows of reducing the roll length to the absolute minimum, this in turn permitting of the relatively small diameter already referred to, and giving quicker

Fig. 3 illustrates this type of manipulator as seen from the front side of a modern cogging mill. It should be noted that a similar pair of side-guards are located at the back side of the rolls, the guards being connected in pairs by through shafts with rack-and-pinion drive, thereby ensuring that when the piece has been guided into the roll pass by the side-guards at the entering side of the mill, the corresponding pair of guards at the delivery side are in line to receive it. Early manipulators of this type were invariably hydraulically operated, but more recently electric drive has been successfully developed, with such advantage as regards ease of operation that on certain recent electrically operated reversing mills in America all movements of the mill are handled by two men in the control pulpit. This has been effected by a combination of hand and foot controlled master switches, arranged in such manner that the man who operates the mill tables also takes care of the screwing gear, whilst the second operator handles the manipulator side-guards and tilting fingers, and at the same time controls the main mill motor with two foot switches, one of which he presses with the right foot and the other with his left, the switches being so interlocked that simultaneous operation is impossible.

It is claimed that this subdivision of the work between two operators only minimises delays and damage through misunderstanding, since No. 1 operator will not travel the piece into the mill before the screwing gear is correctly adjusted, and No. 2 operator is scarcely likely to start up the mill until the piece is correctly lined up with the pass by the side-guards which he himself controls.

Fig. 4 shows the modifications required to make this manipulator suitable for serving a slab mill. It will be observed that the side-guards are deepened for better support of the slab when edged, and cant levers are provided in addition to the tilting-hooks to assist in turning up and lowering the slab. All parts of these manipulators are made amply strong and with operating mechanism of sufficient power to straighten a bent piece, a particularly useful feature in closing up any fish-tail ends which may occur. Table II. gives particulars of various mills in this country which have been equipped with universal type manipulators during the last ten years.

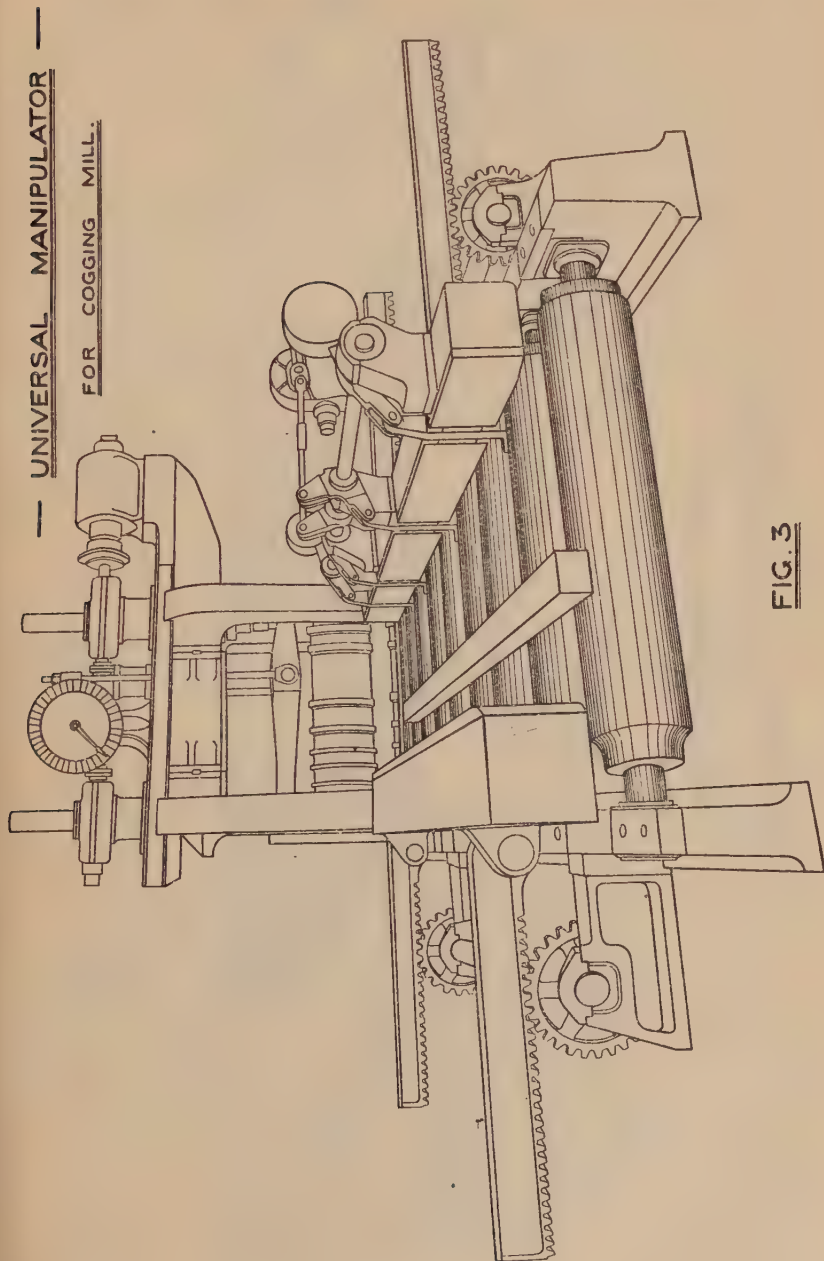


FIG. 3

— UNIVERSAL MANIPULATOR —

FOR SLABBING MILL.

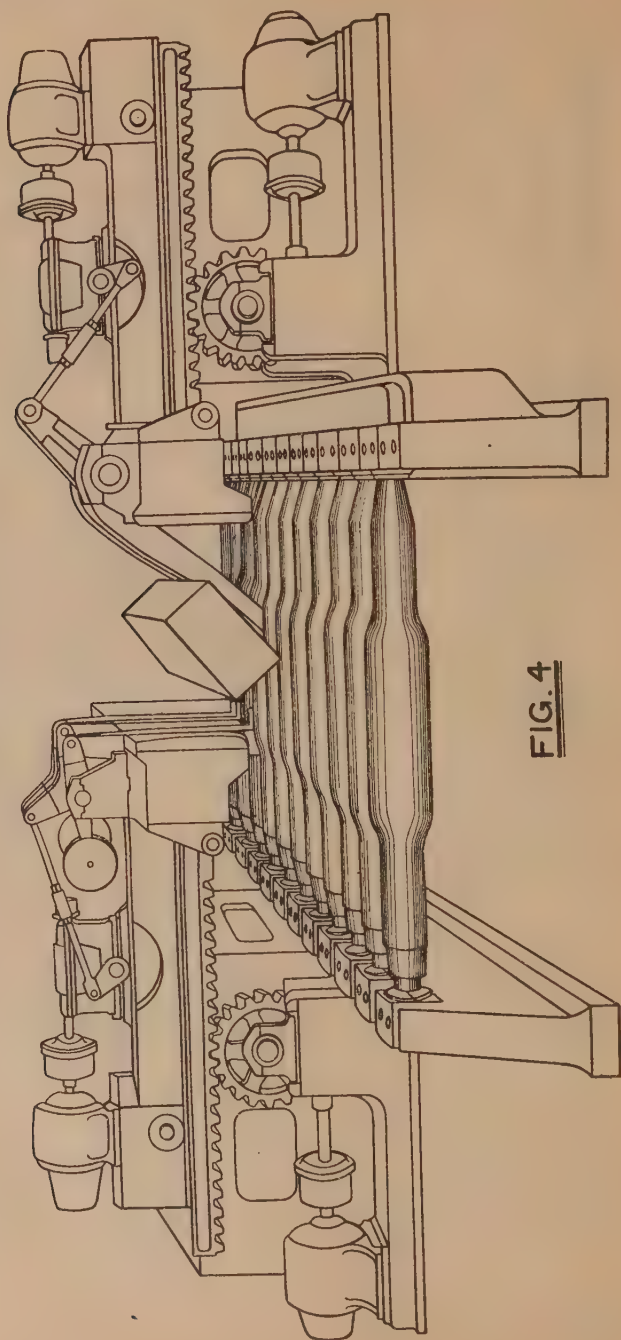


FIG. 4

TABLE II.—*Cogging Mills in the United Kingdom equipped with "Universal" Manipulators.*

Installation at—	Size of Rolls.	Weight of Maximum Ingot (in Tons).	Method of Operation.
Bolckow, Vaughan & Co., Ltd. .	40" × 9' 0"	5	Hydraulic
Bolckow, Vaughan & Co., Ltd. .	42" × 8' 0"	3½	Electric
The United Steel Cos., Ltd. (Templeborough plant)	36" × 7' 0"	3¼	Hydraulic
The Appleby Iron Co., Ltd. .	40" × 9' 6"	20	Electric
Richard Thomas & Co., Ltd. (Redbourn Works, Scunthorpe)	40" × 9' 0"	5	Hydraulic
Baldwins Ltd. (Margam Works) .	36" × 8' 0"	3½	Electric
Pease & Partners, Ltd. (Skeppington Works)	36" × 7' 6"	3½	Hydraulic
The Consett Iron Co., Ltd. .	40" × 8' 6"	10	Electric

In a well-developed plant it should never be necessary to change cogging rolls except for periodical dressing or in the event of accident, the roll profile being such that a full range of slabs or blooms required for subsequent operations may be produced.

LARGE FINISHING MILLS.

Fig. 5 (Plate II.) shows an arrangement of finishing mills used in conjunction with such a cogging mill, and may be taken as representing best practice in this country. It will be observed that two finishing trains are installed, either of which may be worked whilst changing rolls in the other mill. Roll changing is a vital consideration in this class of mill, the wide range of product covered necessitating a stock of probably 250 pairs of rolls. Such conditions obviously call for careful organisation if economical production is to be maintained.

The two finishing trains illustrated differ somewhat in capacity, their respective range of product being approximately as follows :

Three-Stand Mill.

Joists from 8 in. × 5 in. to 24 in. × 7½ in., and all channels and flats within these limits.

Two-Stand Mill.

Joists 5 inches to 8 inches deep.

Channels 5 inches to 9 inches deep.

Bulb angles $5\frac{1}{2}$ inches to 12 inches, andAngles (equal and unequal) from $3\frac{1}{2}$ inches to 9 inches.

The average output of finished product usually realised from such a combination of mills may be taken as about 3500 tons per week of sixteen eight-hour shifts. It should be mentioned, however, that on favourable orders with minimum roll changing, larger tonnage could be readily obtained. A noticeable feature of this plant is found in the spacious finishing and stocking bays, also the convenient and economical facilities for despatch of product by either rail or sea.

During more recent years, with higher cost of construction, the tendency has been to install single finishing trains only, what would otherwise appear to be retrograde practice being to some extent compensated by improved design and mechanical construction. A good example of this class of mill may be cited in the 36-inch rail and section mill at Messrs. Baldwins Ltd., Margam Works, which is now being taken a step nearer completion by the addition of a reversing motor drive at the end of the train remote from the steam-engine formerly constituting the only driving unit.

Whilst no revolutionary changes have occurred in structural and rail mill practice in this or other countries during the period under review, many improvements have been effected in mechanical details of plant which have greatly stimulated output and enormously reduced manual effort. In view of the difficulty in handling long pieces, rolls have been designed to eliminate turning over the piece as far as ever possible, particularly as regards the finishing rolls.

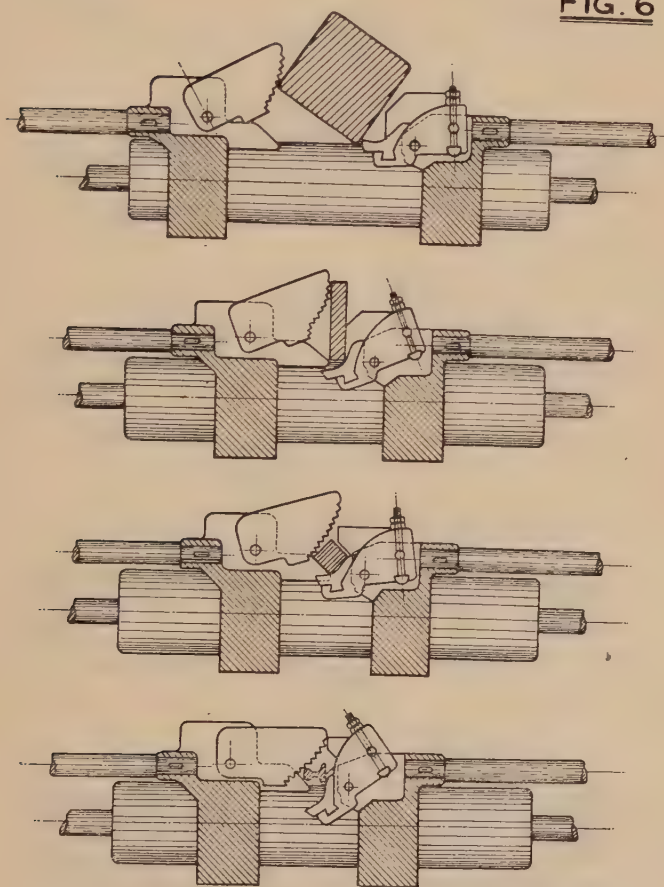
In our latest reversing mills, plain guide pushers are provided at these rolls, and manipulators at the first and second roughing stands. Several successful types of the latter have been developed since the original of Evans and Lewis, these being illustrated in Figs. 6, 7, and 8, whilst Fig. 9 shows a type found useful for the 180° forward-and-backward turns given to tram rails, &c., at the finishing rolls.

Much attention has been given to roll-changing facilities,

housings and fittings being on the latest mills so arranged that a pair of rolls can be completely changed with very little dis-

— "WILLIAMS" MANIPULATOR. —

FIG. 6



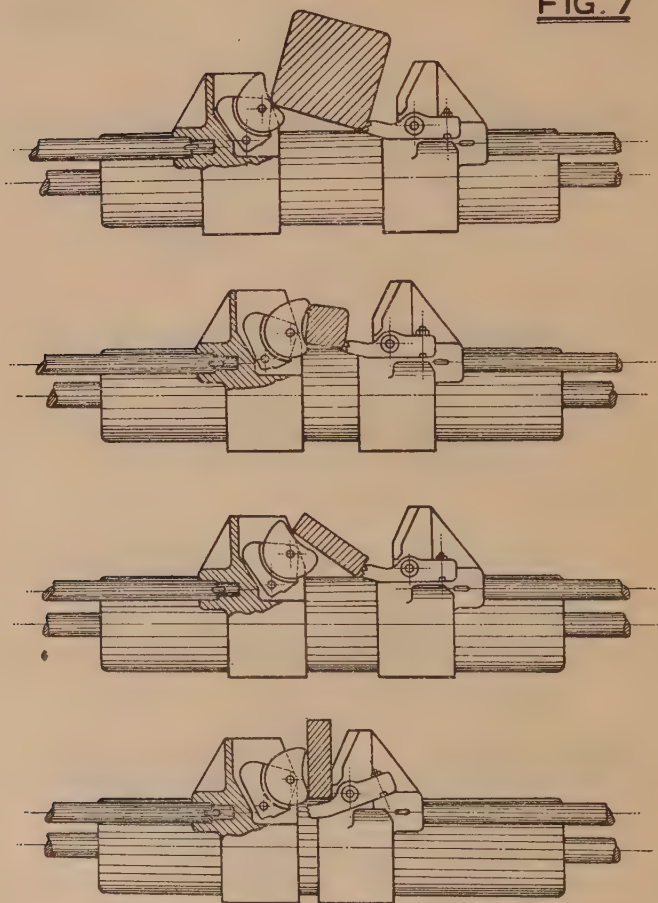
turbance of chocks and driving spindles, the whole operation taking about thirty minutes only.

Fig. 10 (Plate III.) illustrates such a housing design, the arrangement also incorporating a hydraulically operated spindle

positioning and coupling-box sliding gear, which has proved particularly useful in manipulating these parts during roll-changing operations.

— " DAVIES " MANIPULATOR. —

FIG. 7

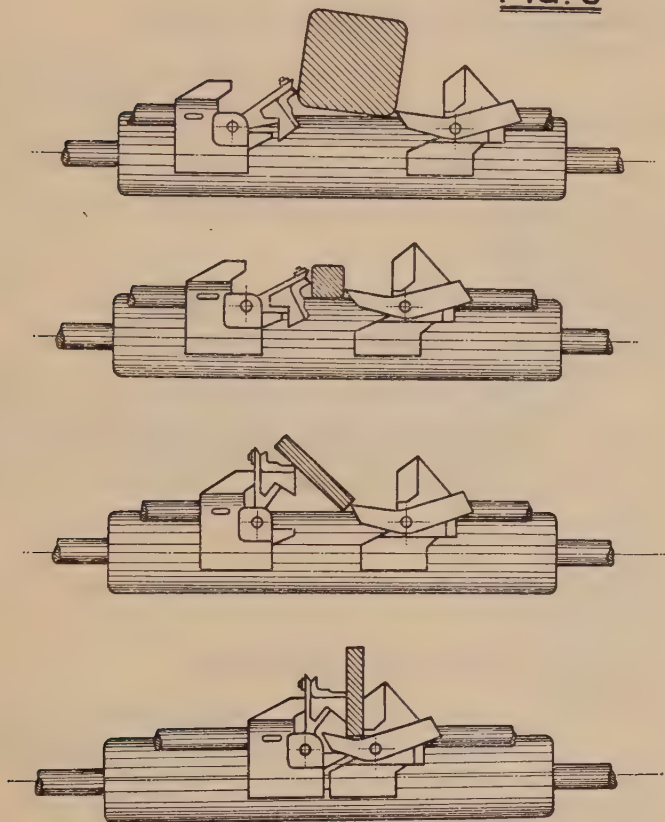


Whilst considering features of construction, reference might be made to another device which, where applicable, results in considerable economy in the use of neck-bearing material. Fig. 11 illustrates this device as used on a cogging mill.

As usually arranged, the housing chocks are provided with endwise "setting-up" facilities, so as to allow of the grooves in the two rolls being readily adjusted in correct relationship.

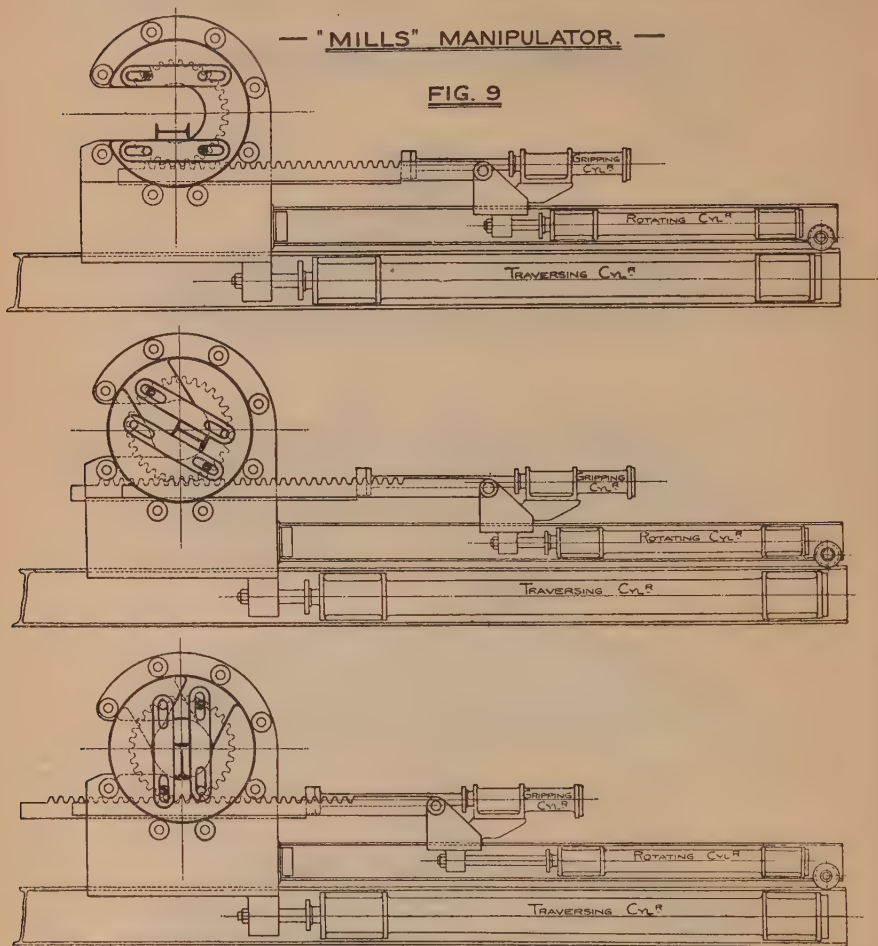
— "THOMAS" MANIPULATOR. —

FIG. 8



With every care and allowance for lengthwise expansion of the rolls when hot, considerable end pressure is found to be exerted on the inside faces of the bearing steps, resulting in these being frequently worn away long before the steps have otherwise reached the renewal stage. In the improved arrangement illustrated, the

roll is retained in position at one end only by means of an adjustable outside cap, which in conjunction with the inside face of the



roll barrel constitutes in effect a double-collared journal bearing, and allows the other end of the roll to be left well clear and free to expand. Incidental advantages are derived from simplified adjustment of the roll through dealing with one end only, and from considerably reduced screwing power owing to minimised friction on roll chock slides.

Since the introduction of heavier ingots, reheating the clogged bloom has become standard practice at most rail and section mills, considerable advantage being obtained as regards control of finishing temperature and appearance of finished product in certain qualities of steel. Such reheating can usually be effected with fuel expenditure of about 112 lbs. of producer-coal per ton

— ROLL ADJUSTING DEVICE. —

PATENT N° 217369

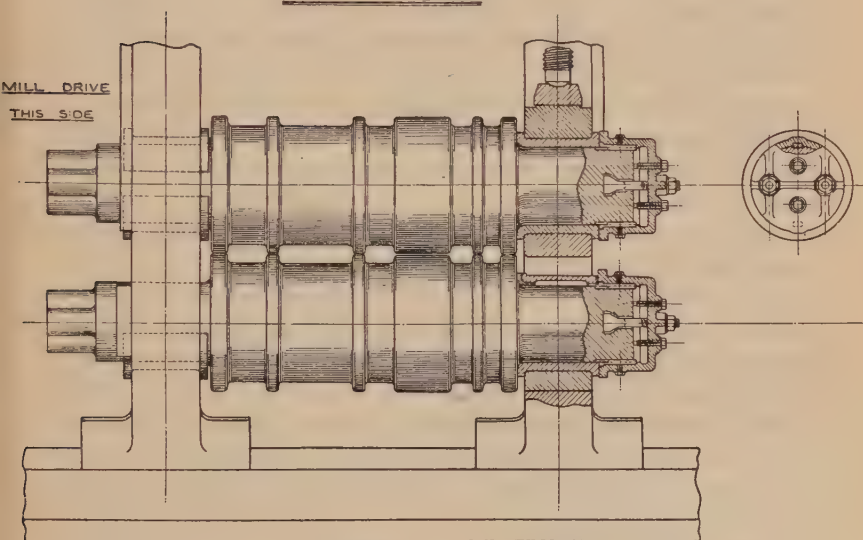


FIG. 11

of product, or more economically still if blast-furnace or coke-oven gas is available.

At many British plants sections and rails are produced on the same mill, the cooling banks, finishing machines, and stockyards being suitably arranged. In America, where many separate plants come under a central control, this practice has been to some extent abandoned, and whilst the three-high mill is generally used for both products, these are seldom demanded from the one mill. Making due allowance for specialisation, however, it must be admitted that American management would demand plant

capable of higher output than is obtained from section mills in this country.

In America structural material is almost invariably finished on three-high mills, the type of plant generally favoured comprising a 40-inch to 44-inch reversing blooming mill, a reversing roughing mill of somewhat lighter construction, and a two or three stand three-high finishing train equipped with travelling tilting tables.

New installations of this type are at present being installed at the Homestead Works, Pittsburg, and also the Lackawanna plant of the Bethlehem Steel Company. An interesting feature of this latter installation is found in the use of a reversing type mill motor for driving the three-high mill. This results from experience gained in the use of a reversing type drive on a similar mill at the plant of the Inland Steel Company, Indiana Harbor, it being claimed that the complete control of mill speed attained allows of the more gradual entry of the piece into the rolls, usually considered advisable with deep flange sections.

In a recent report the author is informed that this latter plant is producing about 28,000 tons of structural material and rails per month. The blooming mill unit is said to have established a month's record of 77,000 tons from 22 in. \times 24 in., 25 in. \times 28 in., and 25 in. \times 36 in. ingots. Further, this mill has rolled forty-four ingots of the latter size, representing 350 tons of steel, in one hour into 6-inch slabs. Most of the rail mills in America were developed during the period of enormous railroad expansion, and can only be considered as speciality mills designed for huge output of a single product. It appears questionable whether such installations as the Gary rail plant would be repeated under present conditions, as freight rates enter so largely into total cost that rolled products must be manufactured to some extent at points of consumption. Apart from the unique plant at Gary, probably the most truly typical American rail mill is that at the Lackawanna Works of the Bethlehem Steel Company. This plant is illustrated by Fig. 12, and has some sentimental interest for British engineers, inasmuch as, in spite of considerable reconstruction generally, one of the mills is still operated by British engines sent out to America forty years ago. (See Plate IV.)

On visiting this plant a few years ago, the author was informed

that the normal production of 100-lb. flat-bottomed rails was 50,000 tons per month, or 900 tons per twelve hours, the record output up to that time being 1570 tons in twelve hours. All flat-bottomed rails are hot-cambered as delivered on to cooling banks.

The rail finishing department contains thirteen straightening machines, two drills being conveniently located to each straightener. The output from each straightening machine is stated to be 100 tons per twelve hours. No end-milling is done on the rail.

The following may be taken as normal rolling practice at this plant:

The ingot 19 inches square at large end receives one pass through No. 1 and No. 2 blooming rolls, these running continuously in the one direction, and the ingot being turned automatically after each pass.

On reaching No. 3 blooming mill usual reversing practice obtains, the piece leaving this mill as an 8-inch bloom after receiving four further passes. The bloom is then side transferred, and the forward end cropped before entering the back end for first pass in the roughing mill, this latter constituting the first forming pass.

After three passes in the roughing mill, the back end of the bloom is cropped and a further pass taken *en route* to No. 1 finishing mill.

Four passes are made in this latter, the piece then being side transferred for final pass through No. 2 finishing mill, making fifteen passes in all.

The crop discard on the ingot averages $12\frac{1}{2}$ per cent.

Fig. 13 (Plate IV.) illustrates a combination rail and structural mill installed many years ago at the Steelton plant of the Bethlehem Steel Company.

It will be observed from the layout that this plant comprises a 44-inch reversing blooming mill, a 35-inch reversing roughing stand, a two-stand 28-inch three-high intermediate mill, equipped with travelling tilting tables, and a 28-inch two-high continuously running finishing stand, all units being independently driven.

The plant is generally considered one of the best combination

mills yet installed in America, and is well suited to a high output of rails.

The two-stand three-high train is equipped with five travelling tilting tables, four of which are used in rolling structural material, the fifth being of special design, which is brought into action at the delivery side when rails are being rolled. This table, in addition to the usual travelling and tilting features, is provided with fixed narrow rollers in line with the last bottom pass, which permits of two pieces being worked in the finishing rolls simultaneously.

At the time of the author's visit to the plant, rails only were being rolled, 105 lbs. per yard flat-bottom section being produced from an 8 in. \times 8 in. reheated bloom in ten passes, five in the 35-inch reversing mill, three in the roughing, and two in the finishing stand of the 28-inch three-high mill. The separately driven two-high finishing stand is used only for special deep rail and tram sections.

In accordance with usual American practice, spare stands of housings are held at this plant, a build-up gang of about six men being employed in fixing up rolls and guides in these, so as to eliminate unnecessary delays in roll changing.

The output of this mill plant has been quite recently stated as approximately 900 tons per ten hours, and 45,000 to 46,000 tons per month.

The total labour force for the blooming mill, rail mill, and all auxiliary services comprises 360 men for two ten-hour shifts per day.

PLATE MILLS.

The relative advantages of three-high continuously running and two-high reversing mills have been much debated, opinion being still divided, and practice in the United Kingdom agreeing fairly closely with that obtaining generally throughout Europe. It is somewhat significant, however, that several of the plate manufacturers who have been longest in the business are now favouring the three-high mill. Table III. gives leading particulars of such mills already installed in the United Kingdom.

In America the reversing plate mill, except when used as a "rougher" in tandem with a three-high finishing mill, or for

rolling universal plate, is practically unknown, the three-high type being very highly developed. Based on actual observation, the author is of opinion that such mills will give an equally good

TABLE III.—*List of Three-High Plate Mills in the United Kingdom.*

Installation at—	Size of Rolls.	Approximate Peak Horse-Power, including Flywheel Effect available at Mill for Rolling Plates of Average Length.	Drive.
William Beardmore & Co., Ltd. (Moss-end Steelworks)	29½" and 21½" × 7' 8½"	4,000	Medium speed motor geared to mill Slow speed flywheel
James Dunlop & Co., Ltd. (Calderbank Steelworks)	28" and 19" × 7' 0"	2,500	Steam turbine geared to mill Slow speed flywheel
The Parkgate Iron & Steel Co., Ltd.	28" and 18" × 6' 6"	1,600	Steam-engine direct coupled
Baldwins Ltd. (Panteg Works)	28" and 18" × 7' 4"	1,600	Steam-engine
Port Talbot Steel Co., Ltd.	25½" and 19" × 6' 0" (Two stands)	3,000	Steam-engine direct coupled
Bolckow, Vaughan & Co., Ltd.	36" and 24" × 9' 0"	10,000	High - speed motor and flywheel geared to mill
David Colville & Sons, Ltd. (Clyde-bridge Steelworks)	36" and 24" × 9' 0"	13,000	Reversing type motor direct coupled
The Consett Iron Co., Ltd.	32" and 22" × 6' 6"	7,000	Medium speed motor and flywheel geared to mill

product as regards finish, and it is a moot point whether by taking advantage of the possibility of slightly barrelling the small middle roll to suit the contour of the top and bottom roll when worn, plates of more even thickness may not be rolled.

The latter consideration is of vital importance in all plate mills, as any excess in thickness of the plate at its centre beyond the usual tolerance of, say, 5 per cent. results in the purchaser being presented with steel for which the manufacturer, of course,

receives no payment. In admittedly good practice this may amount to a by no means negligible weight of steel per week. Such contingency has been to some extent guarded against in certain of the more recent mills installed in Great Britain by using rolls of considerably increased diameter for a given length of barrel, thereby minimising "spring" to the greatest possible extent.

Whilst there are still many obsolete British plate mills, it can with perfect justification be claimed that the new plants laid down in recent years embody all the best features of modern practice. Manual effort has, in fact, been perhaps more completely eliminated in certain of these mills than in any similar foreign plant. This claim applies in particular to the shearing of plates, formerly a most arduous operation, but now entirely mechanical for all other than irregularly shaped or sketch plates. Very naturally, in an individualistic country, differences of opinion exist, and various methods of shearing are in use, each of which has proved advantageous for particular conditions, and to which reference is made later.

Fig. 14 (Plate V.) illustrates a well-arranged plate mill plant laid down a few years ago on the north-east coast. Ingots of 5, 7, or 10 tons are normally worked, the plant having been laid out, however, to deal with 16-ton ingots when required.

This installation comprises a 42 in. \times 10 ft. slabbing mill, a 42 in. \times 9 ft. 6 in. two-stand reversing plate mill, and a universal mill capable of rolling universal plate from 15 inches to 42 inches wide, and up to 90 feet in length. Sheared plate up to 6 feet wide may also be produced in the usual manner by removing the vertical rolls from the mill. This combination of mills has proved easily capable of a production of over 4000 tons of sheared plate per week, about 75 per cent. of this being rolled on the large reversing mill.

In a modern sense the universal mill illustrated is the first of its type to be set to work in Great Britain, but having regard to the organisation to which it belongs, and the fact that another mill of somewhat greater capacity is being installed by well-known tube makers in Scotland, it would appear that former objections to the use of universal plate in Great Britain were largely based on prejudice. The most valid of these objections,

the difficulty of obtaining long plates with the two sides sufficiently parallel and straight as to dispense entirely with shearing or planing, has long been overcome by the development of effective side-straightening apparatus, which handles the plate immediately after leaving the mangle rolls, and before reaching the cooling bank. The product of the universal mill illustrated is sold to a tolerance of $\frac{1}{16}$ inch side curvature only on a length of 5 feet.

The reversing plate mill at this plant comprises two stands of rolls of identical size, 42 inches diameter by 9 feet 6 inches long, these proportions being similar to those of a somewhat earlier mill in the same district, and another quite recently installed still farther north.

On earlier mills of the two-stand reversing type, it was generally the custom to make the roughing somewhat longer than the finishing rolls, so as to allow of some "cornering" of the slab during the earlier passes when roughing down for plate width. This practice, whilst to some extent advantageous as regards limitation of length of finishing roll, considerably increases roll cost from an operating viewpoint, and it is now preferred to have both sets of rolls of identical size, so as to allow of those used for finishing being transferred to the roughing stand for still further duty when the whole of the chilled surface has been removed through frequent redressing.

With this procedure the roll life is prolonged at least 50 per cent., average practice for rolls of the size referred to yielding, say, 35,000 to 45,000 tons in the finishing stand, the life being increased to about 75,000 tons by further use in the roughing housings.

The above figures refer to rolls dressed by lathe, as is most usual in home practice. It is probable, however, that the adoption of grinding would result in still further increased life.

As an indication of what has been done in this direction, it might be mentioned that on a well-known modern 36 in. \times 110 in. three-high plate mill in America, the first main roll discarded is reported to have rolled 108,000 tons after having been in the grinding machine twenty-one times and reduced $1\frac{1}{16}$ inch in diameter.

Reverting to Fig. 14, it will be seen that "Ennis" shearing tables are in use, a more detailed view of these being shown by

Fig. 15. These tables really constitute an extension of the roller table beyond the end-cut shears, the plate after having its ends squared being run through the shears and carried by the "Ennis" table direct to side-cut shears. The table illustrated is provided with two sets of feed rollers, each set being separately driven, so that opposite direction of rotation will turn the plate completely round for trimming of both edges. Interposed between the rollers are transverse skids fitted with magnetic tops, which serve the double purpose of placing the plate in position and clamping down whilst being sheared.

By way of comparison, it might be mentioned that the shear referred to is operated by two men only, one of these controlling all movements of the shear and "Ennis" table, the other being occupied in the removal of scrap. This particular equipment has sheared 131 tons of plate in an eight-hour shift as compared with 181 tons at the castor-bed shear at the other end of the cooling bank, and on which a gang of eight men are employed. The cooling banks at this plant are of novel construction, the plates being supported on rows of disc rollers and transferred over these by "Ennis" magnetic skids. It is claimed for these devices that any plate in the bank may be moved in either direction with the minimum of mechanism, it being only necessary to run the skid under the plate and grip this by energising the skid magnet.

At a somewhat similarly arranged plant not yet completed in the Lincolnshire area, another novel shearing system will be employed. This plant comprises a 40 in. \times 9 ft. 6 in. slab mill, a 40-inch reversing plate mill with roughing rolls 12 feet and finishing rolls 10 feet long, and a single stand reversing mill with rolls 32 in. \times 7 ft. for light plates. This latter mill is so laid out that an additional stand of rolls may be arranged in tandem should future trade conditions warrant the extension.

All mills are to be electrically operated, and, but for the postponement of completion, this would have been the first "all electric" large mill plant to be set to work in the United Kingdom. A novel arrangement of driving equipment has been adopted for these mills, two flywheel converter sets each having four generators being provided for working the three mills, the two converter sets being cross-connected in such manner as to permit

of the combined flywheel effect being utilised to meet the demand of any particular mill. Plates from the cooling bank will be

— " ENNIS " PLATE SHEARING MACHINE. —

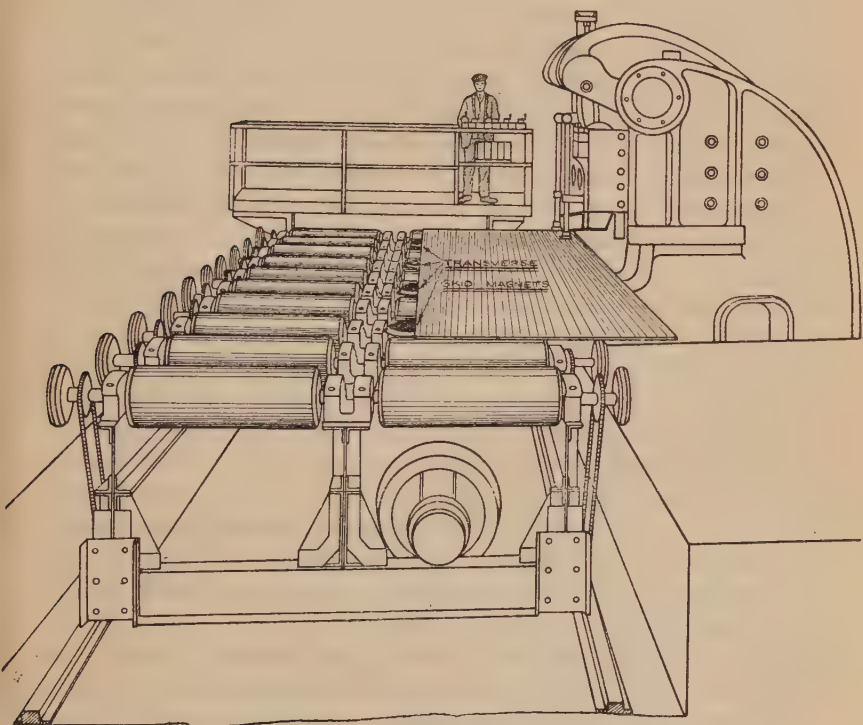


FIG. 15

delivered abreast of the side-cut shears on to a castor-bed served by a " Thomson " plate handling device. This is illustrated by Fig. 16 (Plate VI.), from which it will be observed that the principle involved comprises means for traversing a suspended magnet in two directions parallel and at right angles to the shear blades,

thereby providing all the essential movements of the plate on the castor-bed realised by more arduous manual manipulation.

From quite recent reports, it would appear that the latter consideration is now receiving serious attention in America, where on certain undoubtedly modern plate mill plants a relatively large number of men have been absorbed by shearing equipment.

The author understands that on the 160-inch wide three-high mill plant at the Gary Works of the Indiana Steel Company, not only have magnetic devices been fitted for manipulating the plates on the castor-beds around the side-cut shears, but a mechanical marking machine has been devised which enables one man to mark all plates coming from the mill. This machine runs on a track spanning the run-out table from mangle, the one operator who travels with the machine manipulating by power a suspended arm which traces out the actual chalk lines on the plate.

Plate VII. illustrates a Scottish plant equipped with a single 36 in. \times 108 in. three-high plate mill unit, which would appear to be laid down on practically ideal lines. Comparison with the 36 in. \times 110 in. mill lay-out included in Plate I. will indicate that the breadth of vision rightly credited to mill-owners in America has not been lacking in developing the installation illustrated.

This plant incorporates many novel features, and is probably one of the most efficiently manned mills in existence, practically every known mechanical device for easing manual effort being incorporated. The mill is the first of its type in this country to be operated by a direct connected reversing type mill motor, the primary object of this being to retain the advantages incidental to speed adjustment obtaining on reversing mills. This motor can take peak loads up to 13,000 horse-power.

The mill and all auxiliaries used in actual rolling of the plate are under such concentrated control, that from receipt of the slab from the reheating furnace bay to discharge of the rolled plate to the mangle, every movement is controlled by the roller in charge and two operators stationed in an overhead pulpit, the control of main mill motor, screwing gear, roller tables, manipulation of the slab, side adjustment of plate, &c., being allocated to the two pulpit men, the roller being left entirely free to direct rolling operations and gauge the plate for thickness.

The rolls used on this plate mill are dressed by grinding, which

process, as compared with the more usual method of machine turning, has proved decidedly advantageous in obtaining particularly flat plates requiring the minimum of mangling, owing to the more truly circular roll form obtainable and the practicability of ensuring perfect concentricity of roll barrel and necks. Incidentally, roll life has been considerably prolonged, as the minimum of material is removed from the roll at each dressing operation.

It will be observed that the shearing facilities at this plant are particularly well developed, the plates after passing through end-cut shears being delivered over roller tables to "Ennis" plate manipulating tables serving left- and right-hand side-cut shears at which the respective edges of the plates are trimmed, thereby obviating any necessity of turning round or handling the plate other than by mechanical means.

The side-cut shears are each provided with a small end-cut blade, which cuts up the scrap into lengths suitable for charging boxes at each stroke of the shear. About 70 per cent. of the mill output passes through the side-cut shears, the remainder, constituting irregular and circular plates, being dealt with by the sketch plate shear illustrated.

Other interesting features include a somewhat novel type of skid for the cooling banks, each skid monkey being fitted with a positive skid finger, which can be raised or ambushed through solenoid action as desired. This is a protected device, which has proved very effective in meeting the somewhat exacting conditions of transfer on a plate cooling bank.

Under somewhat trying conditions, and unusually mixed orders comprising a good proportion of thin plates, this mill has already produced 3000 tons of sheared plate per week, and as the slab reheating furnaces have been proved fully capable of each dealing with 1200 to 1500 tons of slabs per week, it will be understood that the above-stated output figure could be considerably increased.

In a comparative sense, this plant is most generously laid out; it is probable, however, that its limiting feature will be found in the space and facilities provided for dealing with finished plates prior to loading and despatch, experience having demonstrated that with such a mill working at maximum capacity, abundance of storage space is a vital necessity.

Under the difficult trading conditions above referred to, it

is, of course, impossible to realise maximum efficiency as regards fuel and power consumption, the latter being much affected by abnormally long periods of idle running of the flywheel converter set. It can therefore be fully accepted that the undernoted recorded figures will be considerably improved upon under more normal conditions of operation.

Fuel at Reheating Furnaces.

1½ cwt. per ton of slabs heated.

Power Consumption.

Main mill drive	.	.	.	.	46	kwh. per ton of finished plates.
All plate mill auxiliaries	.	.	.	.	25	„ „ „ „
<hr/>						
Total	.	.	.	.	71	kwh. consumption per ton of finished plates.

On a mill of identical type and capacity installed somewhat earlier at Messrs. Bolckow, Vaughan & Co.'s South Bank Works (see Fig. 19, Plate IX.), and where mechanical aids to production have also been extensively adopted, a somewhat different shearing system is employed.

At this plant the plate after passing through the end-cut shears is conveyed by roller table direct to rotary disc type shears for side trimming. This type of shear has not found much support in the United Kingdom, probably due to the very varied product of most plate mills, an aspect which has, moreover, been further emphasised by unfavourable trading conditions already referred to. It is interesting to note, however, that the rotary shear is still favoured in American mills, and it is questionable whether for straightforward rectangular plates of moderate thickness its equal can be found as regards tonnage of plate sheared.

As an example of possibilities, it might be mentioned that this particular shear has dealt with 42 tons of ½-inch plate by 7 feet wide in a single hour.

It may also be of interest to state that a shear of this type is being installed for side trimming the sheared plate to be produced on the universal plate mill, previously referred to as being at present laid down in one of the Scottish steelworks.

Whilst on the subject of three-high plate mills, it should be mentioned that on large producing units in America the standard practice is to employ a reversing roughing mill in tandem with

a stand of three-high continuous running finishing rolls. This practice is claimed to increase production very materially, inasmuch as the earlier passes on the short slab can be more rapidly made on the reversing mill, and less frequent roll changing is, of course, required on the finishing stand, owing to the relatively reduced work on these rolls.

To change the small middle roll of a three-high plate mill is a relatively simple matter, this being usually removed endwise through the housing, the change roll being used as a balance weight at the outer end of the coupling-box, by means of which both rolls are slung from the crane during the changing operation. On a well-arranged mill the actual period of stoppage for this operation should not exceed forty-five minutes.

Changing the larger top and bottom rolls is necessarily a more lengthy operation, which has recently received its full share of consideration, and it is possible that in the near future improved means will be introduced for effecting this.

The following figures relating to recorded performance of well-known American plate mills may be interesting, as illustrating production possibilities of modern mills when operated to full advantage :

“ Brier Hill ” Plant, Youngstown, Ohio (32 in. \times 84 in. Tandem Plate Mill Reversing, Roughing, and Three-High Finishing).

Some few years ago this mill in a single twelve-hour shift rolled 299 tons of slabs, averaging 4 in. \times 16 in. section and 560 lbs. weight, into plate, 50 per cent. of which did not exceed 10 gauge in thickness. At a later date, 2332 slabs were rolled in twenty-three hours, and as many as 207 in a single hour, five passes being made in the roughing stand.

“ Mark ” Plant, Chicago (42-inch Wide Universal Plate Mill).

A month's record in the year 1919 amounted to 17,328 tons of universal plate 12 inches to 42 inches wide, averaging $\frac{1}{4}$ inch to $\frac{5}{16}$ inch thick, the yield of usable product being about 90 per cent.

Early in the following year this mill was reported to have established another record by producing 23,000 tons of universal plate in a single month.

*Carnegie Steel Co., Homestead Plant (36 in. \times 110 in.
Three-High Plate Mill).*

During the year 1918 this mill rolled into plate 28,438 tons of slabs in a month of 507 hours actual rolling time, the power consumption over this period averaging only 16 kilowatt-hours per ton for the main mill drive. This plant works from cold slabs, and is equipped with ten reheating furnaces.

Fig. 18 (Plate VIII.) illustrates the latest plate mill plant laid down in this country, its construction and installation being now in process of completion.

This plant comprises a 40 in. \times 8 ft. 6 in. slabbing mill, a two-stand 42 in. \times 9 ft. 6 in. reversing heavy plate mill, a 32 in. \times 6 ft. 6 in. three-high light plate mill, and a chequer plate mill with rolls 6 feet 6 inches long.

The mills and all auxiliaries, excepting only the three shears at the heavy plate mill section, are electrically operated.

These mills have been designed in full accordance with modern ideals, and incorporate in addition to the best of known practice many novel features calculated to ensure rapid and economical production. Plates from $\frac{1}{8}$ inch to 2 inches thick, and up to 8 feet 6 inches wide, will be produced.

The site available for this plant was to some extent limited, and inspection of the lay-out will indicate that the various units have been well arranged so as to provide ample space at all points essential to efficient production. This aspect is particularly emphasised in the spacious loading bay as compared with the congested area available for this purpose at many older plants.

It will be observed that the chequer plate rolls are located in tandem with the light plate mill, the chequer plate mill being so designed that its rolls may be well ambushed when not in use.

It might be mentioned that the complete development of this plant constitutes somewhat of a record, less than two years having elapsed since its conception, and during which period the whole site has been cleared of existing mill buildings and machinery, and new levels created.

Simultaneously an existing plant comprising cogging and section finishing mills has been entirely reconstructed and considerably developed for economical production of the full range of merchant and structural sections.

Fig. 19 (Plate IX.) illustrates a large north-east coast mill plant at which considerable pioneer work has been done during the last ten years. The 40-inch cogging mill already referred to earlier in this paper created a new standard of construction for the United Kingdom, and the installation in 1919 of a 36 in. \times 108 in. three-high plate mill in place of the then obsolete two-stand reversing mill no doubt resulted in closer attention being given to the claims of the former type of mill.

At a later date the rail and section mills were entirely reconstructed, and, with the exception of the driving engines, now constitute a complete new plant adapted to a wider range of product.

It will also be observed that the new 40-inch cogging mill has been laid out with the intention of future installation of additional mills for economically reducing its products to relatively small finished sizes.

The ingot capacity of the two open-hearth plants may be taken as 10,000 tons per week, and production of various units of mill plant as follows :

40-Inch Cogging Mill.

Product.	Capacity.
Blooms, trade slabs, &c. . . .	Up to 100 tons per hour

18-Inch Three-High Merchant Mill.

Product.	Capacity.
Angles up to 4 in. \times 4 in. . . .	Average, 1400 tons per week, with a power consumption including all idle running and light load losses of 44 kilowatt-hrs. per ton.
Joists up to 6 in. \times 3 in. . . .	
Channels up to 5 in. \times 2½ in. . . .	
Flats up to 7 inches and sheet bar . . .	
Various special sections	
Fishplates	
Zed bars, &c.	

34-Inch Rail and Section Mill.

Product.	Capacity.
All rail sections	3000 to 4000 tons per week. Average sec- tions.
Tram rails	
Joists from 5 in. \times 4½ in. to 16 in. \times 6 in.	
Channels up to 15 inches	
Flats up to 14 inches wide	
Angles up to 8 in. \times 8 in.	
Bulb angles up to 12 in. \times 3½ in.	
Sleeper plates, &c.	

Complete spare stands of housings are provided at this mill, in which rolls and guides are set up in readiness for quick substitution at the mill when change of section is to be made.

The advantages resulting from reheating the sheared blooms after cogging have not been overlooked in rearranging the rail and section mills, and facilities for further improvement of product are provided by rail cambering equipment and the installation of complete apparatus spanning the cooling bank for treatment of rails by the "Sandberg" sorbitic process when required.

It will be observed that the inspection and stock banks at the plant are particularly spacious, these being served by overhead magnet cranes, the product being loaded into trucks for direct despatch by rail or sea transport from the company's own wharf.

The sleeper plant indicated is capable of producing 1700 sleepers per shift.

Certain features of the 36 in. \times 108 in. three-high plate mill installation have already been referred to in the earlier pages of this paper, and examination of Fig. 19 will indicate the effective manner in which the various units have been arranged.

The mill is efficiently manned, and is easily capable of producing 3000 tons of finished plates per week, this being the limit of slab reheating furnaces only.

The product comprises $\frac{3}{16}$ inch to 1½ inch thick plate up to 102 inches wide.

Inspection suggests a tendency towards complete electrification of all mill plant at these works, the effective development of heat recovery from blast-furnaces, open-hearth and soaking pits, by the use of waste-heat boilers, having demonstrated that energy almost sufficient for all mechanical working of the steel

is obtainable as a by-product of those processes incidental to its manufacture.

In the author's opinion, the class of mill which has received least consideration in this country is that devoted to production of the smaller rolled products, many works otherwise well equipped being quite unable economically to convert any considerable portion of their output into relatively small sizes.

Some attention was focused on this subject during the reading and discussion of Mr. J. P. Bedson's paper on continuous mills read before this Institute twelve months ago.

Admittedly considerable improvement has been made in the mechanical details of mill trains, methods of driving, &c., with some resultant increase of output, but the fundamental factors associated with feeding of hand-worked mills and difficulties in dealing with long rolled lengths in their hot state impose a very definite limit of production on this class of mill.

Fig. 20 (Plate X.) illustrates a group of small mills of recent installation which may be taken as representative of good average practice.

It will be observed from the lay-out that the plant comprises an 18-inch train with two stands of rolls and a 10-inch train of five stands, the latter being fed from a separately driven 18-inch roughing mill.

All roll stands are three-high, with the exception of the finishing of the 18-inch train (which may be worked two- or three-high) and the last two stands of the 10-inch train, these being top and bottom two-high respectively for oval and finishing rolls.

18-Inch Mill.

This train works on billets or blooms from 3 in. \times 3 in. to 7 in. \times 6 in. section and 34 inches to 72 inches long, the maximum weight being 840 lbs., this latter being the maximum weight considered to be consistent with economical output. All material is man-handled from the time it leaves the furnace until sawn to length.

The product of the mill comprises :

Rounds from $1\frac{1}{2}$ inch to 4 inches diameter.
 Equivalent squares.
 Hexagons.
 Flats from $2\frac{1}{2}$ inches to $7\frac{1}{2}$ inches wide.
 Angles from 2 in. \times 2 in. to $4\frac{1}{2}$ in. \times $3\frac{1}{2}$ in.
 Tees, &c., and
 Pit rails 16 to 36 lbs. per yard.

The highest output of finished material realised has been 32 tons of 4-inch flats in eight hours, the average for any prolonged period being about 20 tons per eight-hour shift.

Taking one example of a week's rolling, 285 tons of finished material have been rolled in sixteen shifts. During this period twelve pairs of rolls were changed and twelve different sections produced.

Power consumption may be taken as about 105 kwh. per ton, this figure including main mill motor, with all auxiliaries, including crane and lighting service.

Furnace fuel consumption dependent on mill output, class of steel, &c., varies from 2·5 to 3·5 cwt. per ton of steel charged.

It should be mentioned that the finishing stand of this mill is usually worked two-high, using stock rolls from a discarded mill, and it is probable that full adoption of three-high rolling would considerably increase output.

The total labour force comprises twenty-four hands, including two boys, per shift, this number covering all services from furnace charging to loading of product inclusive.

10-Inch Mill.

This train is fed from an 18-inch three-high roughing stand, this latter taking billets from 3 inches square to $4\frac{1}{2}$ inches square, 27 inches to 72 inches long, and 400 lbs. maximum weight. For the majority of sections rolled in this mill, the 18-inch roughing stand supplies a billet in lengths which are sheared into two bars by the shears situate midway between the two mills.

The five-stand 10-inch mill comprises bolting, gothic, strand, oval and finishing rolls, and produces :

Rounds $\frac{1}{2}$ inch to $1\frac{3}{8}$ inch.
All equivalent squares and hexagons.
Flats from $1\frac{1}{2}$ inch to $2\frac{1}{2}$ inches wide.
Angles from 1 in. \times 1 in. to 2 in. \times $1\frac{3}{4}$ ins.
Tees, &c.

The highest output of finished product realised has been 32·5 tons of $1\frac{1}{8}$ -inch rounds in eight hours, the average output over any prolonged period being 17/18 tons per shift.

Taking one week as an example, 204 tons of finished steel were rolled in thirteen shifts, which gives an average of 15·7 tons per

shift. During this period thirty-nine pairs of rolls were changed and thirty different sections produced.

Power consumption on this output averages 142 kwh. per ton, including main mill motor, all auxiliaries, crane, lighting service, &c.

Furnace fuel dependent on mill output, class of steel rolled, &c., varies from 2.25 to 3 cwt. per ton of steel heated, the figures including fuel burnt in getting furnace ready for the first shift.

All material rolled in this mill is man-handled from leaving furnace until cropped or sawn to length.

The total labour force for the mill comprises twenty-nine hands, including six boys, per shift.

In considering the performance of this group of mills, it should be appreciated that with widely varying and small orders comprising some proportion of high carbon steel, large output is scarcely possible, recognition of this no doubt accounting for the still extensive use of hand-worked mills in all countries. There appears to be, however, a stronger tendency in certain other countries towards the use of special mills designed for large production with low conversion cost at maximum yield, and the probable effect of this on the world's markets should not be lost sight of.

Fig. 21 illustrates the only comprehensive plant yet installed in the United Kingdom for production of large tonnage of small sections with the minimum expenditure of power, fuel, and labour in conversion from the ingot.

This plant was laid down for a normal production of 40,000 tons per month, the whole of which must necessarily pass through the blooming mill illustrated.

The latter takes a 7000-lb. ingot, 21 inches square at base, and reduces this to $7\frac{1}{2}$ inches or $6\frac{1}{2}$ inches square in thirteen or fifteen passes respectively.

Although adverse trading conditions have not allowed the above-mentioned output being continuously realised, the following table of typical performances will indicate that under normal conditions of operation the designed output is assured.

It will be observed that the plant is arranged with great flexibility, permitting of a wide range of product for direct

sale or feeding the merchant bar, strip, and wire rod mills illustrated.

Working Period.	Number of Ingots Rolled.	Total Tonnage.	Tons per Hour.	Average Power Consumption. Kilowatt Hours per Ton.	
				Mill Motor.	All Auxiliary Services.
Short week, 81.3 hours	2168	6776	83.35	17 to 18.5	6
Best ten-hour shift	282	875	87.5		
Best short period, three hours	115	360	120.0		
Best one-hour run	42	130	130.0		

Products of the blooming mill, such as slabs up to 18 in. \times 6 in. and large blooms, are side transferred to No. 2 shear and discharged direct into trucks, whilst medium-sized blooms requiring good finish may be run forward to the two-stand 21-inch Morgan mill located in line with No. 2 shear. This mill will produce in closed gates blooms 5 inches, $5\frac{1}{2}$ inches, and 6 inches square, direct from the cogging mill, and relatively small edged slabs and large billets requiring specially good finish, previously passed through the first group of continuous rolls situated ahead of No. 1 crop shear.

21-Inch Billet Mill.

It should be appreciated, however, that the principal producing unit is the Morgan continuous billet mill located in tandem with the blooming mill, this being designed to absorb easily the entire output of the latter.

The first section of this mill comprises four stands of 21-inch rolls. These are arranged with three lines of passes, the near side taking a $7\frac{1}{2}$ inch square bloom, and the far side a $6\frac{1}{2}$ inch square bloom, producing respectively $4\frac{1}{2}$ inch and 4 inch square billets. The centre pass line takes a $6\frac{1}{2}$ inch square bloom and produces an 8 in. \times 2 in. slab, or, if desired, still narrower slabs may be made by starting with a somewhat smaller bloom. Billets of the size above referred to may be side transferred immediately after leaving the 21-inch mill, or delivered straight ahead to a second group of continuous rolls 18 inches diameter for further reduction.

18-Inch Billet Mill.

This mill will produce $3\frac{1}{2}$ inch, 3 inch, $2\frac{1}{2}$ inch, 2 inch, $1\frac{3}{4}$ inch, and $1\frac{1}{2}$ inch square billets, also a range of small slabs without change of rolls.

The product of this mill up to $3\frac{1}{2}$ in. \times $3\frac{1}{2}$ in. billets is dealt with by a flying shear, which cuts up the billet into 15 to 30 foot lengths as it leaves the finishing stand of rolls, the speed of delivery in the case of $1\frac{1}{2}$ inch or $1\frac{3}{4}$ inch square billets being about 600 feet per minute. The whole ingot length when sheared is automatically assembled by means of an ingenious arrangement of skew rollers, and receiving straight edge before side transfer to cooling bank.

A most important feature of these mills is found in the possibility of producing the smallest size billets without any limitation of output, the usual size being $1\frac{3}{4}$ inch square. This particular size of billet has been more or less standardised in America from consideration of utility, inasmuch as a $1\frac{3}{4}$ inch square section constitutes the midway point of reduction normally covered by hot-rolling—in other words, a 7000-lb. ingot reduced to a $1\frac{3}{4}$ inch square billet, and this latter still further reduced to a No. 5 gauge wire rod, each representing about 100 elongations.

This system of billet production is practically universal in America, and accounts for about 80 per cent. of all small billets made in that country.

The advantage gained at the cogging mill is obvious, inasmuch as the smaller sizes which so seriously restrict output are absolutely eliminated.

In many instances in America and other countries, where still higher outputs have been specified, the first group of continuous mills have been increased to 24 inches diameter rolls so as to receive an 8-inch bloom from the cogging mill, thereby further relieving the work on this latter unit. The output figures already given in connection with the blooming mill apply equally to the billet mill—in fact, the highest output stated refers to the production of $1\frac{3}{4}$ -inch billets.

*Power Consumption.**Averages for Billet Mills.*

From 34 kwh. per ton for $1\frac{1}{2}$ inch square billets	} Main mill
to 12 kwh. per ton for 4 inch square billets		motor.
3½ kwh. per ton all auxiliaries, excepting only the steam-driven flying shears.	

The labour force for the cogging and billet mills with all auxiliary services, including soaking pits, billet banks, cranes, mechanical forces, &c., comprises 160 men for a single ten-hour shift. It should be remembered, however, that under present difficult trading conditions a large number of men are engaged in breaking, chipping, and handling special quality billets, &c., and as, moreover, other labour concerned with maintenance and heating is necessarily disproportionate on single shift operation, it can be safely assumed that under more favourable conditions much more economical operation will be possible. It might be mentioned, however, that the total number of operators actually engaged in working these mills, from receipt of the ingot from soaking-pit crane to delivery of the finished billets on cooling beds, comprises twenty-four hands, including five boys, per shift.

The economies resulting from producing billets in this way are obvious, as quite apart from considerations affecting labour, power consumption, &c., great economy is effected in fuel consumption. Loss of steel, as compared with other methods of shearing the mill product, is also very considerably reduced. In fact, this might be claimed to be the irreducible minimum, as beyond the usual ingot crop the only discard is the relatively short crop from each end of a finished billet, extending in the smaller sizes to a length of 700 feet.

The fuel consumption, which is, of course, limited to that required for the soaking pits, may be taken under present intermittent conditions of operation as about 168 lbs. of producer-coal per ton of ingots. With the plant working at full capacity this would certainly be reduced to, say, 100 lbs. of fuel per ton.

This mill lay-out is equally suitable for a high output of sheet bars, the usual arrangement being to substitute complete spare roll stands for the second group of continuous billet rolls, the entire change being made in about four hours.

Beyond bringing into action two sets of edging rolls at the 18-inch mill group, no change in mill operation is required for making sheet bar, this being cut up by the flying shear in exactly the same manner as billets are sheared, the product being automatically assembled in stacks equal to about three ingots by means of pinch rollers and a sheet bar piler, and thence transferred to cooling bank by overhead crane.

It is estimated that in America 44 per cent. of all sheet bar made is rolled on continuous mills, and this to a tolerance within $1\frac{1}{4}$ per cent. above or below specified weight.

In view of the importance of the sheet and tinplate industry of the United Kingdom, it is difficult to understand why sheet bars are still rolled here from relatively small ingots on reversing mills at a probable conversion cost from the ingot of 25s. to 30s. per ton, when our American friends have now for many years been rolling these in mills such as that described at a much lower figure, and this with wage rates and other costs very much higher than those obtaining in this country.

The advantages derived from rolling long lengths are well known, these being strikingly illustrated in the case of the merchant bar, strip, and wire-rod mills, also comprised in the Templeborough plant.

These mills are each equipped with Morgan type reheating furnaces adapted for billets 30 feet long, and at maximum capacity will operate continuously on a fuel consumption not exceeding 150 lbs. of producer-coal per ton of steel heated.

Merchant Mill.

Billets used in this mill vary from 2 in. \times 2 in. to 5 in. \times 5 in., and slabs may also be used for production of wide flats.

The mill will produce :

Rounds from $\frac{1}{2}$ inch to $2\frac{3}{4}$ inches diameter.
All equivalent squares.
Angles up to 3 in. \times 3 in., and
Flats up to 8 inches wide.

It will be observed from the lay-out plan that roller tables are provided for each of the four stands of the finishing mill, the rollers of these tables being ingeniously arranged in skew fashion, so as when reversed to cause the piece to hug the side of the table leading into the next roll guides, thereby eliminating manual manipulation.

Readily removable repeaters are also provided for the back side of the mill, these being used on all rounds not exceeding $\frac{3}{4}$ inch diameter.

When working up to full capacity of the heating furnace,

this mill will produce 30 tons per hour continuously, and is usually rated at about 12,000 tons of product per month of average sizes, typical performances being given in the following table :

Working Period.	Product.	Total Tonnage.	Tons per Hour.	Average Power Consumption. Kilowatt Hours per Ton. Mill Motor and all Auxiliary Services.
One week's run of 102 hours	Rounds $\frac{11}{16}$ inch and upwards	1933	18.95	This necessarily varies with size of product. <i>Averages :</i> 140 kwh. per ton for $\frac{1}{2}$ -inch rounds, down to 40 kwh. per ton for $2\frac{3}{4}$ -inch rounds.
One 9 $\frac{1}{2}$ -hour shift	$\frac{1}{2}$ -inch rounds	117	12.3	
One 11-hour shift	$\frac{3}{4}$ -inch rounds	258	23.45	
One 11-hour shift	1 $\frac{3}{8}$ -inch rounds	297	27.0	
One 11-hour shift	2 in. \times $\frac{5}{8}$ in. flats	281	25.5	

The above figures cover all stoppages, including roll changing in the instance stated, during an entire week's run.

Forty-eight men per shift are required for complete operation of the mill, the number including gas-producer attendance, billet-yard men, mill operators, weighman, and labour concerned in handling finished product.

Not the least important feature of this mill is the double mechanical cooling bed. Rolled bars are directed by means of a switch in the run-out from the last pair of finishing rolls alternately to one side or the other of the bed, on which they are mechanically stopped, cross-transferred, and assembled in multiples for delivery to the cold shears. The construction of the rocking racks of these cooling beds results in the rolled bar being contained in continuous V-notches throughout its 300-foot length, and during the whole period of cross-transfer.

Moreover, as the piece is retained in the notches in opposition to gravity, ideal straightening conditions are ensured, and perfectly regular treatment is given to every piece rolled.

On leaving the cooling beds, the pieces, as already stated, are mechanically assembled, cold sheared in multiple lengths up to 75 feet long, and discharged by mechanical push-off into bundling pockets mounted on weigh scales, and from these lifted by overhead crane direct to trucks or stock.

As an example of the possibilities of this type of plant, it might be mentioned that a similar mill installed at the works of the Youngstown Sheet and Tube Co., Ohio, U.S.A., has produced in a single month of 1924 13,506 tons in $48\frac{2}{3}$ twelve-hour shifts, totalling 584 hours, equivalent to 277·57 tons per shift and 23·13 tons per hour.

A similar mill of somewhat smaller size at the same plant, in the same period, has produced 11,030 tons in seventy-three eight-hour shifts, totalling 584 hours, equivalent to 151·08 tons per shift and 18·88 tons per hour, the product comprising a large proportion of rounds $\frac{1}{2}$ inch diameter and under, also small flats.

Strip Mill.

The mill illustrated receives billets from $1\frac{1}{2}$ in. \times $1\frac{1}{2}$ in. to 3 in. \times 3 in., also slabs, and has a range of product varying from 1 inch wide by 0·030 inch thick to $5\frac{1}{2}$ in. \times 0·092 in., the designed output being about 6000 tons per month.

The following table indicates recorded performances under somewhat difficult trading conditions :

Working Period.	Product.	Total Tonnage.	Tons per Hour.	Average Power Consumption, Kilowatt-Hours per Ton. Mill Motor and all Auxiliary Services.
One week's run of 46 hours	Miscellaneous sizes	915	19·89	This is dependent on section rolled, varying from : 250 kwh. per ton for 1 in. \times 0·036 in. thick to 100 kwh. per ton for 4 in. \times 0·064 in. thick
One 9 $\frac{1}{2}$ -hour shift	3 $\frac{5}{8}$ in. \times 0·064 in. thick	184	19·36	
One 9 $\frac{1}{2}$ -hour shift	2 $\frac{1}{8}$ in. \times 0·039 in. thick	140	14·73	
One 9 $\frac{1}{2}$ -hour shift	2 in. to 2 $\frac{1}{8}$ in. wide \times 0·06 in. to 0·08 in. thick	160	16·8	

Forty-one men per shift are required for complete operation of the mill, this number including gas-producer attendance, billet-yard men, mill operators, weighman, and labour concerned in handling finished product.

It will be noted from the lay-out plan that the mill is divided into groups of purely continuous roughing and finishing rolls, with
1925—i.

vertical edging rolls interposed. On leaving the last finishing roll, the strip is automatically turned and delivered through a vibrator in loop formation on edge to a slowly travelling apron conveyor moving in the direction of the coiling reels. This method of delivery permits of dealing with an enormous length in a relatively short space, and presents a maximum surface to the atmosphere, resulting in rapid cooling, at the same time imparting the colour finish usually desired on this product.

The forward end of the strip is entered direct to the reels located immediately beyond the conveyor above referred to, and after coiling is discharged through a slow-moving muffle conveyor, at the delivery end of which the coil is discharged on to trucks sufficiently cooled for man-handling if required.

The product of this mill may be despatched in complete coils, or passed through uncoiling machines and fed to rotary type shears for cutting into definite predetermined lengths, these being assembled and bundled in accordance with trade requirements.

Rod Mill.

This mill, which is fed with billets $1\frac{3}{4}$ inch to 2 inches square by 30 feet long, produces rods from 6 gauge to $\frac{1}{2}$ inch diameter.

The mill works double strand, or, in other words, two billets are passed through the rolls simultaneously, the actual rolling period from the front end of the billet emerging from the furnace door to the outer end of the rolled rod leaving the last finishing roll of the mill being about fifty seconds.

On normal production of No. 5 gauge wire rod from $1\frac{3}{4}$ inch square billets, this is equivalent to two 300-lb. bundles per minute, an output which can be maintained with perfect continuity—in fact, a production of 170 tons has been recorded over a single eleven-hour shift.

It will be observed from the lay-out that the complete mill comprises seventeen stands of rolls, these being conveniently grouped to allow of flexibility in operation, and a flying shear located immediately ahead of the seven-stand roughing mill for the purpose of cropping the front end of the bar so as to ensure a square, solid and hot end for entry into the intermediate train.

On leaving the last finishing roll, the rod is directed by means of automatic switch devices through closed guide pipes containing flowing water to one or other of the four rod reels, the bundle thence being mechanically deposited on a slow-moving muffle conveyor for discharge to loading dock.

On reaching the discharge end of the muffle conveyor, the bundles are automatically picked up by an ingeniously arranged rod bundle carrier, which travels continuously around the loading dock, the length of this latter and rate of travel being so arranged as to ensure the bundles being sufficiently cool for man-handling on reaching the point at which these are loaded into trucks.

In rolling wire rod the elimination of oxidisation is a vital consideration, and a little reflection will show that this is carried to the fullest possible extent in Morgan mills of the type referred to. In fact, after leaving the roughing mill, very little is seen of the rod until it emerges from the final guide on to the coiling reel, and, moreover, as two-thirds of the billet still remains in the furnace at the time the front end reaches the reel, it will be readily understood that uniform treatment is assured throughout the whole length of the rod, both front and back ends being rolled at the same temperature.

On normal production this mill will produce 15 tons per hour continuously, and requires a complete labour force, including all services, of forty-five men per shift.

Through special considerations obtaining at the time the plant was installed, this mill was arranged with engine drive, and comparative power consumption with the other mills of the plant is not so readily available. It may be taken, however, from recorded data concerning identical mills in America, as about 100 kwh. per ton, this figure including main mill and all auxiliary motors. The yield of good rod averages 95 to 97 per cent.

As an example of possibilities, it might be mentioned that a Morgan mill of similar type installed on the Continent as far back as 1908 produced in a recent year 114,000 tons of wire rod, 95 per cent. of this output being No. 6 gauge.

The following table, giving monthly analyses of this output, illustrates the wonderfully regular manner in which such mills may be worked. This is to some extent reflected in furnace fuel consumption, the average throughout the whole period referred

to being 5 per cent. of the total steel heated, or, in other words, 112 lbs. per ton of product.

Morgan Continuous Wire Rod Mill.

Date.	Production. Tons.	Number of Eight- Hour Turns Worked.	Average Production per Eight Hours. Tons.
May 1923	9,184	75	122
June 1923	9,513	78	122
July 1923	8,680	72	121
August 1923	9,775	81	121
September 1923	9,049	75	121
October 1923	9,888	81	122
November 1923	9,651	78	124
December 1923	9,388	75	125
January 1924	10,343	81	128
February 1924	9,440	75	126
March 1924	9,671	78	124
April 1924	9,487	75	127
Total	114,069	924	123·5

Whilst discussing continuous mills, it will no doubt be of interest to refer to other installations designed for somewhat different product.

Skelp Mill.

Fig. 22 illustrates a Morgan mill of this class recently installed in this country for production of skelp from $1\frac{5}{8}$ in. \times 0·08 in. to $8\frac{1}{4}$ in. \times 0·25 in. thick, the rated capacity being 10,000 tons per month of average sections. (See Plate XII.)

The mill is equipped with a Morgan type furnace of similar efficiency to those already referred to, and arranged to accommodate billets from $1\frac{3}{4}$ inch square and slabs up to 7 in. \times 2 in., all of 30-foot length. Skelp is an ideal product for continuous rolling, the mill, as will be seen from the lay-out illustrated, being of a comparatively simple nature.

A particularly interesting feature of this plant is found in the rotary flying shear, which cuts up the skelp into predetermined lengths as it leaves the last stand of finishing mill, and delivers them on to the discharge conveyor, at the outer end of which a set of pinch rollers assemble the whole billet length in pile formation

for transfer across the mechanical cooling bed. On reaching the outer end of the cooling bed the piles are weighed, bundled, and mechanically discharged into bunkers, from which the overhead crane removes them direct to trucks or stock.

Production of this mill has necessarily been handicapped by adverse trading conditions, which have obtained more or less continuously since starting up. The following table gives some recorded performances which will, however, demonstrate its possibilities :

Working Period.	Product.	Total Tonnage.	Tons per Hour.
One week's run of sixteen shifts	Average sizes	2420	18.9
Single eight-hour shift . . .	$7\frac{1}{2}$ in. \times 0.160 in.	229	28.62
Single eight-hour shift . . .	$4\frac{1}{4}$ in. \times 0.118 in.	201	25.12
Single eight-hour shift . . .	$\left\{ \begin{array}{l} 3\frac{1}{4} \text{ in. } \times 0.124 \text{ in.} \\ 3 \text{ in. } \times 0.109 \text{ in.} \\ 2\frac{5}{8} \text{ in. } \times 0.104 \text{ in.} \\ 2\frac{9}{16} \text{ in. } \times 0.124 \text{ in.} \end{array} \right\}$	116	14.5

On the occasion of a recent visit of the author, the mill was engaged on $6\frac{1}{8}$ in. \times 0.185 in. skelp, and had produced 31 tons of this material in the previous hour.

The yield of good product averages 93 per cent., a good proportion of the discard being saleable at little under billet price.

The total operating force at this mill plant, covering as before all services, numbers forty-five men, including six men on the boiler plant and producers.

The mill is steam-driven, but if electrically operated the power consumption would average 50 to 60 kwh. per ton.

Combination Strip and Skelp Mill.

Fig. 23 illustrates a unique type of Morgan mill installed a few years ago in Newport, Monmouthshire. (See Plate XIII.)

In designing this mill, the originators had in mind the more varied demands of this country, the result being that plant was developed which combined the essential features of the strip and skelp mills already referred to.

Such a venture could scarcely have been in better hands, as

its proprietors, Messrs. The Whitehead Iron and Steel Co., Ltd., have since 1907 been operating with great success a Morgan semi-continuous bar, rod, and hoop mill installed at their Tredegar Works about that time.

Members of this Institute are referred to a very able paper read by Mr. L. D. Whitehead before the Staffordshire Iron and Steel Institute early in the present year, which deals very fully with many aspects of continuous rolling, and describes their two mill installations at considerable length.

Reverting to Fig. 23, it will be observed that the product of the mill can be delivered to strip coiling reels or skelp cooling bed in accordance with requirements, the handling and storage facilities of the building being suitably arranged for dealing with both products.

The output of this mill on 3-inch and 4-inch skelp has reached 200 to 220 tons per eight-hour shift, such tonnage being limited only by furnace capacity when handling relatively large products.

The following figures are typical of normal production on usual strip sizes :

Size.		Output per Eight Hours. In Tons.	Kwh. per Ton. Mill, all Auxiliaries, Lighting, &c.
Width. Inch.	Thickness.		
1	20 gauge	50/55	215
1½	20 "	70/80	200
2	20 "	100/110	155
1	16 "	60/65	180
1½	16 "	90/100	165
2	16 "	120	120
2½	16 "	150	105

The net yield from cold billets after crediting value of scale, scrap, and defectives is 97 to 98 per cent.

No opportunity is missed as regards realising the full possibilities of this plant, recording instruments being used which provide an absolutely reliable record of every operation, the power peaks on the chart (Fig. 24) clearly indicating the degree of uniformity maintained in heating the billets and feeding these into the mill. Concerning the latter aspect, inspection of the following table

will show that the actual production efficiency reaches from 64·4 to 81·12 per cent., this being the proportion of material actually delivered from the finishing rolls as compared with the maximum output which would be obtained if the billets were passing through the mill as one continuous piece.

Size.		Possible Weight per 9½ Hours. In Lbs.	Actual Weight Rolled, In Lbs.	Efficiency per Cent.
Width. Inch.	Thickness. Inch.			
1	0·036	164,160	133,280	81·12
1	0·060	202,771	141,120	70·0
1½	0·036	244,340	182,000	74·5
1¾	0·036	307,800	228,480	74·3
2½	0·062	437,066	316,400	72·5
3½	0·110	728,184	468,160	64·4

The importance of regular feeding cannot be over-emphasised, as inspection of Fig. 24 will show. This is a reproduction of a chart actually taken from the finishing mill motor when rolling $2\frac{1}{16} \times 0\cdot062$ in. strip at high speed.

It will be observed that the gaps between the billets, or, in other words, the depressions in the curve, average, say, 20 per cent. of the total rolling period, but that in some instances this is reduced to approximately 5 per cent., indicating that in such cases billets are fed into the rolls approximately end to end.

Other records clearly refute adverse criticism occasionally made concerning mechanical efficiency of necessarily complicated mill machinery. Running light at full speed this mill with fifteen sets of 12-inch rolls absorbs less than 200 kilowatts, roughly 10 per cent. of the total rolling load, a surprisingly low figure when taking into account the absolute roll rigidity required in rolling such fine gauges as are produced.

For many years continuous mills were employed solely for rolling wire rods, billets, and other intermediate products, and it has only been within the last thirty years that finished products rolled to extreme accuracy have been produced on this type of mill.

That great authority, Mr. Jerome R. George, attributes this comparatively slow development to the fact that the first practical

— MORGAN CONTINUOUS 12' HOOP & SKELP MILL —

WHITEHEAD IRON & STEEL CO. LTD.

POWER CHART FROM FINISHING MILL MOTOR

ROLLING $2\frac{1}{2} \times .082$ STRIP FROM HALF BILLETS

CHART SPEED 6" PER MINUTE

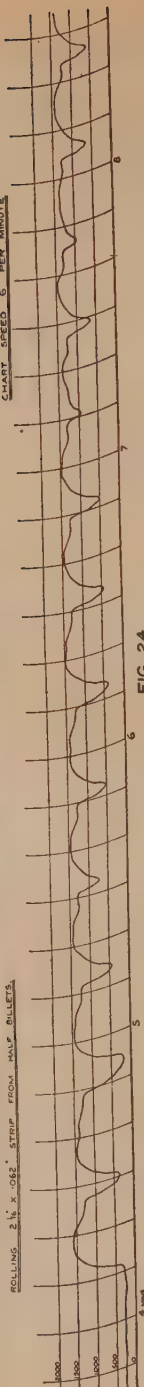


FIG. 24

attempt at continuous rolling was made on a product so small and difficult to make as wire rod, and expresses the opinion that had these earlier efforts been concentrated on the more simple problems of continuous rolling, such as flat products, to which the system is almost perfectly adapted, much more rapid development of the art of rolling generally might have resulted.

The pure continuous mill has one great and fundamental advantage, viz. that, when fixed close to the door of the heating furnace, the time period from the furnace to the last or finishing pass is exactly the same for the first and last end of the billet, regardless of its length and weight, and consequently any length can be finished, and the same weight and temper of the finished piece maintained from end to end, results unattainable in any other type of mill.

Moreover, extended study and application of the principle of continuous rolling is resulting in the discovery of such further possibilities in the combination of continuous and semi-continuous roll trains, that the scope of this type of mill is being constantly widened.

An interesting development may be cited in the case of a mill now under construction, which will have equally good facilities for the rolling of merchant bars, wire rod, and strip, the continuous principle of rolling which is largely employed making this great diversity of product possible without sacrifice of economy.

Amongst other recent developments may be mentioned two purely continuous mills now being designed for the Youngstown Sheet and Tube Company, each of which will have an average capacity of 175 tons per hour, or 22,400 tons per week. Both mills will roll from the initial heat of the ingot, one producing sheet and tin bar in all the commercial weights, and skelp up to $16\frac{3}{4}$ inches wide, the other billets from $1\frac{1}{2}$ inch to $3\frac{1}{2}$ inches square, and a miscellaneous assortment of slabs.

A wire-rod mill is also being built for the Bethlehem Steel Company on which the rod will be delivered from the final pass at 3500 feet per minute.

The author does not propose to discuss sheet mills, cold-rolling, or other types of mill used for non-ferrous metals, as it is felt that the range covered is already sufficiently wide for a single paper.

It is also felt that reference to constructional detail of the plants described would be superfluous, inasmuch as in really modern mill machinery sound engineering is implied.

The old belief that anything capable of turning round was good enough for rolling-mill work is fast disappearing, and scientifically designed machinery is now well established in the leading steelworks of most countries. Such design necessarily embraces the vital considerations of selection of materials of construction, accurate machining of working surfaces, and, possibly more important still, adequate lubrication, with total enclosure wherever possible of lubricated surfaces. These provisions are necessarily reflected on the running of the mill, it now being quite possible to run a complete cogging mill train and its electrical equipment with a power consumption of about 220 kilowatts at light load, probably at least two-thirds of such power being absorbed by the flywheel converter set. The advantages resulting from complete electrification of main and auxiliary drives have been so fully discussed that further comment would appear to be superfluous.

Mention might be made, however, of a recent development already referred to in a paper read by Mr. L. Rothera at the end of 1924 before the Cleveland Institute of Engineers, as this suggests some further development in the construction of mill trains through the possibility of eliminating the driving pinions.

In the new drive suggested the usual double armature reversing type mill motor would be split into two units, each of the two halves being attached direct to the top and bottom line of rolls respectively without interposition of any gearing.

The author was privileged to witness the test of this drive made at Messrs. Pease & Partners' Skinningrove Works, and was much impressed with its possibilities, it being demonstrated by actual rolling operations that the two mill rolls automatically and exactly adjusted their rotation to the surface speed of the material being rolled.

The successful development of this form of drive should prove useful in the operation of mills having roll grooves of such form as make differential speed inevitable, and would also be particularly applicable to the driving of plate finishing rolls, as the top roll could be kept in rotation, and at the same time balanced,

thereby obviating the pronounced shock on the mill experienced with a "jump" roll, as commonly used.

Such developments as have been described, whilst gratifying to many, are disturbing to others, who appear to be under the impression that for some inexplicable reason highly specialised plant is not well adapted to our moderate and varied output. The author would submit, however, that with a population which, in spite of the ravages of a great war, is estimated to have increased by 2,000,000 since 1914, an ever-increasing production must be maintained if such numbers are to be supported. This can only be achieved by unremitting attention to costs of production—a consideration to which the iron and steel producers of America, even with their great natural advantages, are now giving first place.

In this connection it has occurred to the author in reviewing the foregoing pages that, as the best of British plants only have been referred to, a stronger feeling of security than is intended may be conveyed.

In view of this it appears necessary to emphasise that the plants referred to cover practically the whole field of modern development in this country, and as such cannot be considered excessively disproportionate to our needs.

From the necessarily privileged position of business association with many of the schemes projected by competing nations, it can be definitely stated that, unless a more ruthless policy is practised in the scrapping of obsolete plant than has hitherto obtained, it can scarcely be hoped to produce at the cost necessary to ensure sale of the bulk of the home product in the open markets of the world. Admittedly, the present is not the most opportune time for preaching the gospel of expansion, but if the analysis attempted in this paper results in full and useful discussion of what is undoubtedly a vital branch of the British iron and steel industry, its purpose will be well served.

In conclusion, the author wishes to record grateful thanks to the heads of organisations who have so readily supplied information concerning the plants illustrated, his own professional friends, and those personal assistants who have so willingly sacrificed their leisure in helping in the preparation of this paper.

DISCUSSION.

Mr. FRANK ANSLOW (Glasgow) said Mr. Hand had dealt mainly with the developments in the larger rolling-mill plants for steel ingots, plates, and heavy sections, and had brought that subject up to date. Members would agree that the progress made had been fairly satisfactory. In the table of mills Mr. Hand had, however, omitted to mention one or two, particularly the steel plant of the Scottish Iron and Steel Company, which was erected during the period dealt with in the paper. That plant was completely new, with modern rolling-mills, and was entirely electrically driven from mixed-pressure turbines supplied with steam from the adjacent ironworks—an ordinary malleable ironworks as distinct from a blast-furnace plant. Much could be said on the points raised by Mr. Hand with regard to the heavier mills, but he (Mr. Anslow) proposed to limit his remarks to three-high continuous rolling-mills of the 7-inch to 12-inch class, because he thought the present bad state of trade had badly hit proprietors of that class of mill. Many mills of that type had been put down in Great Britain for producing large outputs and rolling cheaply, so long as trade was good and the mills could be kept going; the difficulty was to keep them going, and mills so laid down became costly when trade was bad. Usually they were then shut down because they could not afford to be kept running. On the other hand, mills were put down for producing comparatively small quantities of sections, and were run cheaply, or comparatively cheaply, under the present restricted conditions, but they were unable to rise to the occasion and produce the necessary output when trade was good. The difficulty was for the proprietors of such works to lay down mills which would operate economically under all conditions of reasonable output. In Fig. 20 (Plate X.) a mill was shown which might reasonably be expected to meet those conditions, but unfortunately the particulars given rather indicated that the mill did not rise to the occasion. The output was small and the cost of rolling was naturally high. An average output of 17 to 18 tons per shift was given, with a power consumption of 142 kwh. per ton. A mill of that sort should be capable of producing a very much larger output, and naturally in that case the cost would fall. As Mr. Hand quite rightly said, roll-changing, dealing with so many different sections, caused a small output, but even under those conditions he (Mr. Anslow) thought that in the particular case under discussion the figures were extremely low; in fact, in quite a large number of mills of which he had knowledge the output was easily one-third better and the power consumption at least one-third less. It was possible to get very much bigger outputs in ordinary operation than the maximum output of 32·5 tons per shift, which was given in the paper as a record performance. As the result of his (Mr. Anslow's) experience he had seen

that done. The point was to get the output out of mills which were arranged to give a large output, and the best way of showing that was by means of a curve illustrating the relation between output and rolling costs.

In the diagram (Fig. A) the output and costs were shown for a mill similar to that described by the author. If it were assumed that the 17 to 18 tons output were at point "A" of curve No. 1, and the output were increased by one-third to, say, about 24 tons to point "B" on the curve, a very noticeable reduction of rolling cost was shown. That showed that, on the particular part of the curve indicated—and parti-

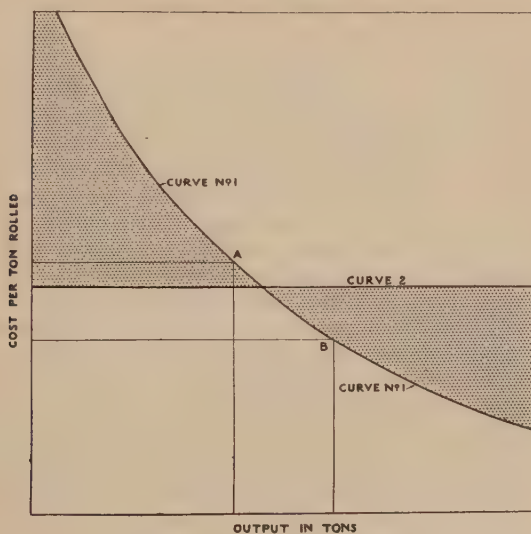


FIG. A.

cularly for the lower outputs—the effect of output was important in relation to cost of rolling. Of course, such a curve could be taken only as applicable to any particular mill, and, not being generally applicable, had to be worked out for each mill, and the conditions relative thereto, individually.

Curve No. 1, showing the cost, was based on the cost of power varying with the quantity used, and the utility of the diagram could be extended by adding curve No. 2, which was a straight line, and assumed that power was obtainable either in the form of steam or electricity at a constant rate, independent of the quantity used. From a comparison of those two curves it was seen at a glance that in times of good trade, when production was high, the cost of rolling was much lower with the variable rate than with the constant rate, as indicated by the shaded

portion of the diagram below the constant rate line. On the other hand, the shaded part above the constant rate line clearly indicated that, in times of bad trade and restricted output, benefit was obtained by the constant rate system of charging for power. By constructing suitable curves for each particular case it was possible to settle what would best meet the prospective rolling conditions of the plant, which was a particularly important matter at the present time, and he emphasised the very important fact that mills should be laid down suitable for producing reasonable outputs—not necessarily large specialised outputs, but reasonable outputs of a wide range of sections, and also that arrangements should be made for securing a supply of power for driving the mills on a basis which best suited the variable conditions likely to be experienced.

Mr. L. D. WHITEHEAD (Tredegar) said he was astonished at the figures quoted in regard to the output of the plant shown in Fig. 20. He thought there must be something special in the conditions described in the paper, because, on exactly the same type of plant in operation at Tredegar (a 10-inch mill, built in 1880), up to 48 tons a shift was being rolled at the present time, and with a three-high Taylor and Farley mill, built in 1900, the mill had been brought up from an output per shift of 25 tons to about 80 tons. That had not been brought about by the introduction of any special machinery at all, but by the introduction of better heating capacity and the important factor of not starting with too large a billet. It would be noticed in Fig. 20 that the mill started with blooms of 7 in. \times 6 in., and that the smallest bloom was 4 in. \times 4 in. That used to be the practice in his (Mr. Whitehead's) own company twenty years ago in the 14-inch mill, but at the present time they were running with no bigger than 4-inch blooms and down to $2\frac{1}{2}$ -inch billets, in lengths of 14 to 16 feet. As a result they had been able to get the output up and obtain good results from the old type of mill. Mr. Anslow had criticised the operation of the continuous mills. His (Mr. Whitehead's) firm had had eighteen or nineteen years' experience of continuous rolling-mills, and it might be of interest if he stated that the Tredegar mill had run nearly 96 per cent. full capacity for the past three years, when trade conditions had been as bad as they could be. It was essential in continuous mill rolling to site the mill in the right place. He was afraid a mistake had been made in Great Britain by building some of the continuous mills inland. From a trade point of view, it was necessary to have a cheap source of supply of billets and facilities for export. At Tredegar they had probably from 40 to 50 per cent. of export trade, and consequently were able to keep the whole plant going. In addition to that they put down at Newport, in times of the very highest cost, a 12-inch hoop and tube strip mill which cost over £300,000, and yet that mill was operating at the present time economically and making as good a return as any mill in the country on its capital. There, again, its site had been an important consideration. It was right on the docks : it received cheap

material from the inland works or from abroad ; and it was able to send out its goods and put them on board at 1s. 6d. a ton f.o.b. In such circumstances it was possible to do a good trade. One point in connection with the paper which struck him very greatly was that insufficient attention had been paid to two very simple but very important factors related to the plant. He referred to the provision of ample railway facilities and ample stocking facilities. It was not the slightest use spending hundreds of thousands of pounds on the most economical plant for the production of steel unless free outlets were given for the product, and innumerable instances could be seen in which that had not been done.

Special attention had been drawn by Mr. Hand to the continuous billet and sheet bar mill. In that direction he (Mr. Whitehead) thought there was a very great opening for the English steel trade—not at the moment, because nobody wanted to spend any money at the present time, but it was possible to look ahead and make plans for the future. There was no doubt that the six-stand continuous 18-inch billet mill, as an adjunct to the finishing mills in steelworks, would be a very valuable asset. It produced a 1½-inch billet at the same cost as it produced a 4-inch billet, except for the very slight extra power cost. It produced it with a minimum of waste, and it furnished the finishing mill with what it wanted—a small billet cheap. The cost of such a mill made in Great Britain was no higher than the ordinary reversing or three-high mill, and it occupied less room.

There was no doubt that it was possible to roll down in a plant of that sort from 4 inches to 1½ inches at a fraction of the cost of rolling in the merchant mill, and so starting in the latter with a smaller billet. There were places in Great Britain where the sheet bar industry was combined with the billet industry and where there was an opening for the introduction of a complete sheet bar and billet mill with a 21-inch roughing mill behind. He hoped that some of his friends, especially in his district, would bear that in mind. As large consumers of billets they would certainly like to see that section of the trade go ahead. He agreed with Mr. Anslow that when the production was brought down to 70 or 80 per cent. of the maximum output, heavy capital charges began to pile up abnormally, whereas in the older type of mill it was possible to fall to perhaps 40 per cent. of output with the same standing charges. With a correctly situated works, and given a cheap supply of billets, there was scope for operating a mill of that type economically.

Mr. L. ROTHERA (London) wished to endorse the statement made by Mr. Hand with regard to the fact that most of the modern drives in Great Britain were capable of far greater outputs than they were now giving, and that the limit was not the capacity of the drive but the lack of steel or lack of heating facilities or handling limitations. The result of such limited output was seriously to increase the capital

charges per ton of steel produced, and, in view of the importance of that item, every effort should be made to increase output.

On p. 48 Mr. Hand referred to a very interesting method of controlling a reversing equipment in America through both hand and foot control, the latter being used for the reverse and speed regulation of the mill motor. It would be interesting to know whether Mr. Hand had seen such a mill in operation, and whether the foot control made the fine adjustment possible that was obtained with the hand control. There was no difficulty in designing a suitable piece of apparatus for the purpose of such foot control if it were considered worth while to instal it, and it certainly saved one, if not two, additional men.

On p. 52 reference was made to the desirability of reducing manual effort. That had undoubtedly been the aim of most of the modern plants, and recently a number had been installed where in place of the usual hand-operated main controller a new device had been supplied whereby the operating lever only set the position of a valve, oil pressure providing the motive power for the movement of the controller. That very materially reduced the labour involved on the driver. In the same way the introduction of master controllers for the auxiliary drives had relieved the operators of the live rolls, screw-down gear, &c., of considerable physical labour.

Reference was made on p. 58 to a drive at the plant of the Inland Steel Company, Indiana Harbor, where a reversing type drive was used on a three-high mill. That same type of drive was installed for the plate mill at Clydebridge, and a great deal of comment had been made in regard to it from the point of view of capital cost involved. Its advantages, however, were numerous and more than counter-balanced the somewhat greater additional cost; not only, as Mr. Hand stated, did it allow of more gradual entry of the piece into the rolls, but it allowed higher speeds to be used for the finishing passes and increased the safety of the mill by giving instant control of the speed and removing the flywheel from the mill to a separate flywheel set. In his (Mr. Rothera's) opinion, and certainly as regards a three-high plate mill, the future would show such a mill operating as a reversing mill for the first eight to ten passes, for the following reasons:

The time lost in the intervals between the earlier passes was high, owing to the short slab, under heavy draught, throwing too far from the mill. In the mill in question the intervals at the beginning would be from four to five seconds, whilst the later passes would be only two to three seconds. A considerable saving in time of rolling would thus ensue. In addition to that, the present pitting of the roll necks so prevalent in a continuous-running mill would be largely avoided by the better lubrication following on the reverse. The wear on the pinions would also be reduced, and the power consumption in rolling would be less, due to saving in friction losses on the mill, whilst the shock on the housings would be materially reduced.

On p. 67 the output from the Clydebridge mill was given as 3000

tons of sheared plate per week, but actually during a week when a trial was carried out over 4000 tons of plate was rolled in that particular mill.

The power consumption given for that mill was 46 kw.h. per ton of finished plate, and as against that, on p. 70, the consumption obtained on the Carnegie Steel Company's three-high mill was given as 16 units. That apparent discrepancy was no doubt explained by the difference in the thickness of the finished product and the increased output from the mill. The figure of 46 kw.h. mentioned in the paper did not represent the best performance which had been obtained on the Scotch plant. When rolling out just over $\frac{1}{2}$ inch thick plates at the rate of 25 tons an hour the power consumption averaged about 27 kw.h. per ton, which would have been improved upon with greater tonnage output. There was no reason why that particular mill should not equal, from the point of view of power consumption, any of the recent mills installed.

Dealing with the size of mills, Mr. Hand had referred to a 44-inch reversing blooming mill. It would be interesting to know whether he advocated the use of such a large mill under existing conditions of British practice. Taking into account capital cost, both of the drive and of the mill itself, there would appear to be no advantage in such a large mill unless much greater draughts were taken than was at present European practice.

Mr. H. B. Tox (Saltburn-by-the-Sea) congratulated Mr. Hand upon his paper, which contained useful details and information regarding the rolling-mill plants which had been installed in Great Britain during the last ten years. Personally, he deplored the fact that a number of the plants which he had inspected were either designed or made abroad. He had many times wondered whether that was the result of neglect in education on the part of our works engineers, or because they were not afforded an opportunity by their employers to keep their works up to date. He was inclined to suggest that the latter reason was too frequently the trouble.

He noticed in the paper an illustration of a roller table, designed by Mr. Ennis, which was now being successfully used for manipulating steel plates for the purpose of shearing each side of the plates, and he thought that all the members who had seen that table would agree with him that it was an excellent invention for the purpose, but the question arose, was it advisable to reverse the plate to shear both sides, and he contended that the shearing might be done more expeditiously and cheaply by installing a shearing machine on each side of the plate. He remembered paying a visit to many works on the Continent with one of the late members (Mr. David Colville) nearly twenty years ago, and they were quite in agreement, from the plate mills they saw, that it was neither necessary to lift nor reverse a plate to shear it, as was the custom in some mills even to-day.

They had been convinced also that the most important details to study in a steelworks were "speed and power," and he thought that if more attention were given to those details in Great Britain a very great economy might be anticipated as the result.

He was not sure that some of those modern plants, referred to in the paper, were applicable for the home demand. The universal mill, which had been in use on the Continent for a great number of years, had only been adopted in Britain recently, for a second time, and there were yet some little difficulties to be overcome before it would be possible to satisfy the demand for perfectly straight plates without a second operation.

He was favourably inclined towards the employment of continuous rolling-mills for producing billets, sheet bars, rails, and similar sections which were required in large quantities, both at home and abroad, and he was strongly of opinion that those particular sections might be rolled more expeditiously and economically in a specially designed continuous mill than in large reversing mills which were at present in use.

Sir WILLIAM ELLIS, G.B.E., D.Eng. (Past-President), said Mr. Hand was a distinguished colleague of his in the company of which he was Chairman, and he wished to take the opportunity of thanking him for the very great amount of work he had put into the paper and the ability he had shown in dealing with a subject of very great interest to the Institute. He (Sir William) was one of those who felt that there was still a great amount of modernising to be done in connection with mill work in Great Britain. He was also cognisant of the fact that unfortunately there were many directors and managers of steelworks at home who would be only too pleased to act in that direction were the state of the industry of the country in a more favourable condition. In other words, the financial aspect was so difficult that they hesitated to bring forward schemes for introducing economies even when they might be fully justified. He urged those gentlemen to have the courage of their opinions, because when an industry was suffering from uneconomic production owing to the low prices ruling, that was the time when expenditure on extensions and improvements was more fully justified. The economies that could be introduced if they were carefully studied would, he was perfectly certain, fully justify the expenditure incurred. He realised, of course, that the industry in its present state could find no justification for large expenditure; but that was a very different thing from doing everything that was possible, by study and examination, to see whether existing plants could not be so modernised as to bring them more closely on a competitive basis in regard to cost of production.

It must be realised that plants which were still actuated by low-pressure steam, possibly some distance from the boiler supply, could not possibly compete with plants electrically driven. That difficulty

was more serious some years ago when there were still so many steelworks without efficient and sufficient supplies of electric power. That had been remedied to a very great extent, and he would urge that the great economy which had resulted from electric driving *versus* steam driving, with regard to machine-shops and shipyards, was also applicable in the case of various mills in steelworks where the mill *qua* mill might be reasonably efficient and yet was an extravagant piece of mechanism because of its source of driving power. That was the half-way house, which did not represent a very large capital expenditure, and in many cases would fully justify itself. He wished to join in congratulating Mr. Hand on the paper, which was a valuable contribution, and fully justified the trouble and time the author had given to its production.

CORRESPONDENCE.

Mr. FRED CLEMENTS (Park Gate) wrote that during the last fifteen years a considerable change had come over practice in rolling-mill design in Great Britain. Previously it was the custom, when anything progressive in mill equipment was required, to go to the United States or to Germany for it, but a revolution had taken place, and now some of the best mill work in the world was produced in Great Britain. In bringing about that acceptable change, the initiative and courage of the firm with which Mr. Hand was connected (Messrs. Davy Bros., Ltd., Sheffield) had played a large part, and Mr. Hand's own ability and energy had been applied to the subject for many years.

It was illogical to take foreign practice and, because it had been successful in another country, apply it directly in Great Britain with the expectation that the same success would automatically follow. It might do so; on the other hand, experience had shown that it frequently did not. To examine practice abroad to the fullest extent was of course necessary, but surely the steel industry of Great Britain was big enough to have its own problems considered and machinery designed to solve them. Each works had its own difficulties and domestic troubles, which often rendered the application of any standard design uneconomical.

The marked difference between conditions in Great Britain, as compared with the United States or Germany, seemed to be in the individualistic character of the specifications available in Great Britain. The opportunity for mass production, whilst successful in some instances, was not present to the same extent. In Great Britain the demand was in the main made up of a mass of relatively small orders, which often, though the sizes called for might be identical, varied in the quality of even the steel required. British mills, therefore, had to have a degree of flexibility and adjustment which was not called for in mass production

plants intended to roll large quantities of material similar in size and quality.

It was difficult to lay down any hypothesis by which the value of a mill might be judged, but surely, as the touchstone of success was the ability to give a fair return on the capital outlay, any plant which was capable of giving a return of profit during a period of depression could be deemed to be satisfactory. It was interesting to note that, judged by that standard, it was the mills which were capable of meeting the conditions outlined which were "weathering the storm."

There were many factors which played a part in the design of the ideal mill, amongst them being the following: Location; character of the orders; quality of the steel; output required; ability of the workmen; efficiency of the management—all of which bore materially on the result; but it would have been instructive if Mr. Hand had given his views on what he considered the right type of plant for a typical set of conditions which he might have outlined. In the examples he gave, he did not provide any critical evidence which might enable an opinion to be formed as to how near they approached the ideal.

Another question on which Mr. Hand was eminently fitted to give an opinion was with regard to the amount of engineering refinement which might be economical in a mill installation. Some of the Continental mills suffered seriously from over-engineering. That was especially true in Germany, which was as might be expected, but in some of the United States plants also, despite the awe which was inspired in the beholder, such a disability was more than suspected. It would be interesting to have a "real" cost of production for comparison.

There must be obviously a limit to the extent to which it was economical to carry engineering refinement, depending on the conditions under which the installation had to operate. Attention was called to the need for the scrapping of obsolete plant and the installation of machinery of modern design, in order that the cost of production might be brought to a level commensurate with foreign competitors. The importance of such a policy could not be emphasised too strongly, although at the moment the irony of the situation was that, whilst many of the new plants were standing, a number of the old ones were busily employed. That, however, was only the case for the present and would pass away with the return to more normal conditions, but it served to stress the need for a careful survey of the conditions of each individual case, and to that end the knowledge of the subject displayed by Mr. Hand made it clear that it was not necessary to go outside Great Britain to obtain the guidance required.

Mr. JEROME R. GEORGE (Worcester, Mass.) wrote that Mr. Hand's paper contained no criticism of the small units in which the steel business of the United Kingdom was largely carried on.

In view of the industrial success which Great Britain had enjoyed

over a long period of years, he supposed it was somewhat dangerous to attack the British individualistic system of working; but in America, and to a large extent in Germany, the greatest development which had taken place in the last twenty-five years had been the consolidation of the industry into large units controlling the entire process from raw material to fine wire and other products prepared for the ultimate consumer. Such a method of working had rendered possible a great many economies, such as economy of heat units, economy of transportation, economy of capital, employment of special machinery, better control of labour on the part of the management, and better opportunities for the working man.

Under the competitive conditions obtaining in America at the present time, it was practically impossible for a small open-hearth steel plant not connected with a blast-furnace and by-product coke works to make any money, however well the steel plant might be built or located. In other words, the margin of profit in ordinary steel products frequently got down to the point represented by the economies inherent in the larger self-contained works.

To his mind there were too many steel plants in Great Britain. Consolidation of the capital invested and of the orders into fewer plants might possibly be the only means of permanent recovery for the steel industry in Great Britain. In other words, the introduction of the most modern and best possible mechanical equipment might not in itself be sufficient to save the situation.

Mr. T. B. MACKENZIE (Motherwell) wrote that Mr. Hand had gone so fully into his subject that very little room was left for criticism, and certainly none for adverse criticism. In Table I. particulars were given of some cogging mills erected during and since the war, from which it appeared that those mills, which were steam driven, had lower torques than those which were electrically driven. Even making allowance for the fact that the steam torques were averages whilst the electric torques were maxima they seemed low, particularly No. 2, with 42-inch rolls and an average torque of only 70 metre-tons.

He was interested to note that Messrs. Baldwins Ltd. were adding a reversing motor to the opposite end of their mill from the engine. That was certainly a step in the right direction.

The roll-adjusting device shown in Fig. 11 was very good and should enable the rolls to be kept in proper alignment.

Coming to the three-high plate mills, Table III. gave peak loads for the eight mills tabulated, and once again the steam-driven mills appeared at a disadvantage.

On Plate VII. was illustrated the general lay-out of the Clyde-bridge mill belonging to Messrs. David Colville & Sons, Limited. That mill was driven by a reversing type motor which could take peak loads up to 13,000 horse-power. As the engineer who was, more than anyone else, responsible for advising the firm to adopt that drive, and

as he had seen it criticised more than once, he (Mr. Mackenzie) might perhaps be allowed to give the reasons which led to its adoption. During visits paid to German steelworks before the war, he learned that it was sometimes the practice in that country to drive three-high mills with reversing engines without flywheels, so that the speed of the mill could be varied to suit the requirements of the mill. That seemed to him to be a very good idea, and when the Clydebridge mill was being designed he suggested getting a price for a reversing drive to compare with the more usual type of drive—namely, a high-speed motor and flywheel with gearing capable of taking suddenly applied peak loads of the same order of magnitude. That was done, and it was then found that the difference in cost was so small as to be more than justified by the undoubted advantages of the reversing motor. The directors accordingly gave their consent to the scheme, and they certainly had no cause to regret their decision. The reversing drive not only enabled the speed of the mill to be varied to suit the requirements of the work being done, but when any little adjustment had to be made the mill could be stopped practically at once—in less than one revolution of the rolls—and when waiting for material—which happened now and again even in the best regulated works—the mill did not need to be kept running at full speed, but could be slowed down to creeping speed, thus reducing wear and tear. He quite agreed with Mr. Rothera that output would be increased by taking the initial passes reversing. What the effect on the rolls would be was another matter. Probably one slab would have to be rolled between the bottom and middle roll, and the next one between the top and middle roll, so as to give them an equal amount of work. The ideal arrangement, however, was no doubt to have a reversing stand in front of the three-high mill, as by that means a slab could be broken down in the reversing mill whilst the previous one was being finished in the three-high mill.

He noted that at Lackawanna a reversing motor was being used to drive a three-high mill; there could be no doubt that it was the correct thing to do. No one who had had experience with the flexibility and convenience of the reversing drive would ever want to have anything else.

Reference was made in the paper to a recent development which was referred to in a paper read by Mr. Rothera before the Cleveland Institute of Engineers—namely, driving the bottom and top rolls independently by dividing the usual double armature motor into two single armature motors. That, when he read the paper, seemed to be a good idea, and he was glad to see that Mr. Hand had seen it at work and was able to report favourably on the drive. In the case of the hard rolls of plate mills with “jump” roll, the blow on the end of the housing screws was most severe, especially when thick plates were being rolled.

The ruthless scrapping of obsolete plant was a policy with which he (Mr. Mackenzie) was heartily in agreement. Why firms persisted

in retaining plant which could never again hope to compete with modern plants, unless for the benefit of the County Assessors, it was hard to see. It would be a very poor plant indeed where the value of the scrap would not more than pay for the demolition. The only cure for those old plants was for—

“ Ruin’s merciless ploughshare to pass o’er
And barren salt be sown upon the site.”

In conclusion he desired to thank the author (Mr. Hand) for his very interesting and instructive paper.

Mr. R. MATHER (London) wrote that he thought perhaps the most important statement in Mr. Hand’s interesting and valuable paper was that he had covered “practically the whole field of modern development” in Great Britain. That was approximately correct; and the fact that so small a proportion of British steel was rolled in efficient mills went far to explain the difficulties of the industry in meeting the competition of other countries. That became still more evident when it was realised that even of the mills described only a few (with the exception of the plate mills, which were generally being worked with relatively good efficiency) produced the high outputs which would be expected of such plant in other countries. For example, Mr. Hand reported that one American mill was producing 28,000 tons of structural sections and shapes per month. Was there any one mill in England producing more than half that quantity of such material? Again, probably no blooming mill in England other than that at Templeborough could be worked even in times of good trade at a monthly rate of output at all comparable with that of the American blooming mills described, the limitation being either in the supply of ingots or in the capacity of the finishing mills to take the blooms. The relatively greater output of finishing mills abroad was due in part to the wider prevalence of direct rolling of the blooms—blooms used, that was, without reheating. That avoided the checks and delays involved in handling the blooms into the reheating furnaces, and again from the furnaces to the mill. It was doubtful that everything possible had yet been done to eliminate those delays and other disadvantages incidental to the handling of blooms by charging machines into and out of reheating furnaces. It would probably be practicable to develop continuous pusher furnaces sufficiently to enable them to handle hot blooms direct from the mill and to make the movement of the blooms from the mill through the furnace to the finishing mills almost automatic. By such a method hot blooms could be supplied to the finishing mills as quickly as the blooming mill could produce them, and with greater regularity and at less cost than by present methods.

Those who, like Mr. Hand, believed that further development of continuous rolling was possible, might be interested to hear that in India a continuous mill had been used for rolling sleeper plate $\frac{7}{16}$ inch thick

in the middle, $\frac{5}{16}$ inch at the sides, and with beaded edges. It was, however, doubtful whether Mr. Hand was correct in assuming that in continuous rolling the same weight of the finished piece was maintained from end to end. In some products, at any rate, the middle of the piece was frequently smaller in width and thickness than the ends, to an extent requiring careful attention where narrow limits had to be adhered to.

The relative inefficiency of British merchant mills was clearly shown in the statistics of imports of steel into non-producing countries, most of which drew an enormous preponderance of their bars from Continental countries, the discrepancy being more marked in that product than in any other. Nothing but a thorough revision of British merchant-mill plant and practice could be expected to remedy that condition.

Mr. F. SCARF (West Bromwich) wrote that the need for such a contribution was evident, and such a paper as Mr. Hand's was long overdue. He (Mr. Scarf) could have wished that the paper had dealt more fully, however, with the smaller type of rolling-mills. There were no examples of that class of mill given in the paper, except the two mills at Park Gate and the continuous mills. Surely in Sheffield, Staffordshire, and Lancashire there must be some modern mills worthy of description. It would have been very interesting to have heard exactly what Mr. Hand had to say on that point. If there were no such mills, his remarks as to the backwardness of British mill practice in that respect were amply justified.

Although the consumption of billets and sheet bars in Great Britain was about 4/5,000,000 tons per annum, there was only one billet mill described in the paper, and he (Mr. Scarf) was afraid there was good reason for that. The author gave the probable conversion cost from ingot to billet or sheet bar in Great Britain as 25s. to 30s. a ton, and that agreed exactly with the result of his (Mr. Scarf's) own inquiries. He believed that in the best billet mills on the Continent the cost was rather less than over 15s. a ton, and it was difficult to believe that the higher wages paid in Great Britain could account for more than 2s. 6d. per ton at the most. If Mr. Hand could give any reason for that very large difference in the cost of rolling down it would be extremely useful and timely, and its value would be enhanced if he could give some estimate of that cost in the Templeborough mill running, say, at 80 per cent. full. Mr. Hand's praise of the continuous mill, coming as it did immediately after the recent papers of Mr. Bedson and Mr. Whitehead, seemed to indicate a general opinion that there was no halting-place between the old types of rolling-mills and the continuous mill. He (Mr. Scarf) wished to urge some reasons against coming too hastily to that conclusion. Among the disadvantages of the latter were its enormous capital cost, its heavy wear-and-tear expenses due to the high speeds at which its finishing rolls ran, its unhandiness for jobbing work, and the extremely high technical skill required in its management. The American dictum

quoted in the early part of Mr. Hand's paper that "The investment cost per unit of annual production is approximately equal for all classes of mill machinery" could hardly apply to the continuous mill. He would estimate that, notwithstanding its huge production, the capital cost per unit must be two or three times more than that of other good modern mills. It could not be looked upon as a great labour-saver, except from the point of view that the dividing tonnage factor was a large one. Two and a half years ago he visited America and saw the chief continuous hoop and strip mills, and recently he visited the Newport mill, and all of them were alive with men. All had the same excuse, that a large staff was necessary for roll-changing; but that did not alter the fact that every man appeared to be busily engaged. Those mills formed a striking contrast to a 10-inch hoop mill installed some four years ago by the Carnegie Steel Company outside Youngstown. In that mill the steel was not handled until it reached the bundlers' benches, the mill staff were very few in number, say four or five, and all of them were sitting comfortably at lesiure, not even watching the mill; very different too to the cat-and-mouse attitude characteristic of continuous mills. He made those remarks, not in any depreciation of the product of the Morgan firm, which had his unstinted admiration as an engineering *tour de force*, but as the expression of a belief that in the straight-in-line continuous mill a good principle had been pushed too far, and that for British conditions and specifications its desirability had not yet been established.

Mr. G. P. WEST (Glasgow) wrote that Mr. Hand referred to an important point as to the relative efficiency of three-high *versus* two-high reversing mills. It was difficult by actual observation to arrive at definite facts regarding the proved efficiency of one type against another, seeing that the two types were not in any case, so far as he (Mr. West) was aware, run under precisely the same conditions, either due to layout of the plant, the different items of auxiliary plant employed, varying weights of slabs, length, width, and thickness of plates rolled in respective mills, and other items which would affect the final results from the mill. Advantages and disadvantages could, in some respects, be claimed for both types.

Advantages with the three-high mill which it appeared could be directly referred to were that the speed of rolling was maintained throughout each pass, and the return of the plate into the rolls could be effected very rapidly, that being particularly the case from the top to bottom pass, immediately the plate had attained a length of about 10 feet, for at that point the tables could be lowered before the material was entirely through the rolls.

In the short slabbing passes the tables could not be dropped, and the high speed of the rolls might be considered a disadvantage rather than an advantage.

It therefore appeared probable that the ideal combination would be

to slab down on the reversing and finish on the three-high principle, which view appeared to be supported by the practice in America, to which reference was made by the author. That being accepted, the three-high mills would appear to have obvious advantages, for they could be adapted to run both as reversing and three-high mills.

As regarded the quality, uniform thickness, and flatness throughout the length and breadth of the plate, it had been proved that the three-high mill was quite efficient to meet those requirements—indeed, the results in some mills had been found to be excellent, probably superior to those obtained from some reversing mills; but in regard to such points as those, an important bearing was the general lay-out of the racks, cooling beds, and auxiliary plant. Mr. Hand referred to the fact that in the three-high mill weight might be saved by barrelling the middle roll to suit wear of the top and bottom rolls. He (Mr. West) might also mention that the fact of being able to change the middle roll very speedily was an important advantage gained without a corresponding loss of time.

Mr. HAND, in his written reply to the discussion and correspondence on his paper, referred to Mr. Anslow's expression of regret that the plant of the Scottish Iron and Steel Company had not been referred to. He (Mr. Hand) was aware that considerable reconstruction had been carried out at those works, but would explain that in presenting the paper he had been obliged to impose some limit as to length, and had taken such examples only as appeared best to illustrate present conditions in rolling-mill practice. As regarded output of the small mills illustrated in Fig. 20, he quite appreciated that instances could be cited of similar-sized mills yielding much greater output. On the other hand, it had to be remembered that many similar mills were producing less, and he thought the figures as stated in the paper were not far wrong for average practice. In his opinion, the reasons for such low production were not far to seek; they were manual handling of the material throughout, and great diversity of product. The value of the latter consideration always seemed to him to be a very doubtful quantity, and for that reason he could not altogether agree with Mr. Anslow's views respecting the type of mill he would install. The proper function of a mill was to roll steel, and all time spent in changing section meant reduced earning capacity. Moreover, provided work was obtainable, it would generally be found profitable to install additional plant rather than overcrowd a mill with products beyond the range which could be economically handled by its auxiliaries. He quite agreed with Mr. Anslow, however, concerning the effect of output on production costs, that being much more far-reaching than the economy of power only, shown by Mr. Anslow's diagram. It should be remembered that in a general sense the conversion of bloom or billet to finished section represented a definite expenditure of energy, and whilst with increased production some proportion of the light load losses were eliminated,

the greater economy resulted from spreading the dead charges on the plant over a larger tonnage.

The low output on the small mills illustrated had likewise been referred to by Mr. Whitehead, who had been good enough to explain the methods by which he had enormously increased production on similar mills installed at his Tredegar plant. That was exactly what he (Mr. Hand) would have expected from a man of Mr. Whitehead's progressive character, and he would commend the further experiences and possibilities referred to by Mr. Whitehead to members' very serious consideration.

In the very interesting remarks made by Mr. Rothera, the question was raised whether he (Mr. Hand) had actually seen the combined hand and foot control of a reversing mill motor in operation. He was not able to reply in the affirmative, as that system had been introduced since he was in America, but from reliable reports concerning increased output due to better co-ordination of control, there appeared to be no doubt of its success, and if the analogy of operating an automobile were taken, where, in changing down, a skillful driver would almost unconsciously make seven separate movements of hand and foot in less than a second, there would not appear to be any difficulty in obtaining by foot control the delicate adjustment to which Mr. Rothera referred. He was inclined to agree with Mr. Rothera concerning the future possibilities of the reversing motor drive to a three-high mill, and was looking to some experience being made in that direction in the near future. With reference to power consumption on the three-high mill mentioned, the figure of 46 kw.h. per ton appeared high, but, as stated in the paper, it represented the average over a full week's operation on somewhat unfavourable orders, and also covered all idle running of the plant. The lower figure of 16 kw.h. given in connection with the Carnegie Steel Company's mill referred to slab weight only, and at 75 per cent. practice would represent 21 kw.h. per ton of finished plate for the main mill drive. It should be explained that that figure was realised during a month of very large output, when approximately 28,000 tons of slabs were passed through the mill and rolled into plates of fair average thickness. That performance, however, emphasised the effect of output on power costs. As regarded the 44-inch blooming mill referred to, he wished to explain that that was an American rating, and therefore referred to pinion dimensions. As a matter of fact, such a mill would correspond to a 40-inch blooming mill as used in Great Britain.

Certain of the new mill plants installed in the United Kingdom were referred to by Mr. Toy as either designed or manufactured abroad. Fortunately that aspect was not so damaging to British engineers as might appear on the surface, as, with the exception of the Morgan type of mill which was designed abroad, but now built in Great Britain, and one or two universal mills, the purchasers of which did not seem to have confidence in British engineers, the whole of the new mill plant

described had been entirely designed and built at home. The question of shear tables and of turning round the plates was a matter of judgment. If the lay-out of Messrs. Colville's Clydebridge plate mill were referred to, it would be seen that two tables were used, serving right- and left-hand shears, thereby obviating any necessity of moving the plate other than for adjustment of the shearing edge. Mr. Toy had questioned the utility of the universal plate mill for home conditions. Personally, he (Mr. Hand) thought it was a little belated in its arrival. So far as he knew, the product of the mill at Redcar was serving quite a useful purpose. Another mill had recently come into commission in Scotland for rolling wide tube strip, and it was fully expected that the usable product realised would be about 90 per cent. of the steel fed into the mill, as compared with about 75 per cent. when working with sheared plate. That was an aspect well worth considering.

He had to thank Sir William Ellis for speaking in support of the paper, and he thought the point Sir William had touched upon, of the present being an opportune time for converting admittedly obsolete plant, was a matter deserving very serious attention on the part of responsible steelworks management. There were plants in Great Britain which time had depreciated to such an extent that overhead charges were undoubtedly low, and with the very moderate demand obtaining under present depressed conditions, such plants could without doubt be operated economically. The time would come, however, when such plants would have to be scrapped. On the other hand, competitive nations were improving their equipment rapidly, and at the present time several continuous sheet bar and billet mills similar to the one at Templeborough were being started up in northern France: a wire-rod mill of the latest type had just come into commission, a strip mill was to start very shortly, and after that a merchant mill. In Belgium there was being installed one of the finest combination rod, strip, and merchant mills that could be designed. In purchasing that mill the experts responsible for its selection did not go to the cheapest market, but after investigating all possibilities throughout the industrial world, decided on what they considered the very best mill that could be selected for the purpose in view. The point he wished to make was, that if Continental nations, such as France, Belgium, and Spain, could do that sort of thing (and America had done it for many years), how was it that Great Britain, the home of the iron and steel industry, had still to be content with working many plants laid down forty to fifty years ago?

Certain statements were made by Mr. Clements which should give great encouragement to British steelworks engineers. He had also drawn attention to the marked difference in conditions obtaining between our home and foreign steel industry. In his (Mr. Hand's) opinion many of those differences would have to be eliminated if the British industry were to prosper. It was well to be proud of British traditional skill and quality of product, but it was inevitable that with

every advance in the general standard of living the main demand must come from the masses of the people, whose requirements could reasonably be met by methods of large-scale production alone. He appreciated Mr. Clements' suggestion that more detailed criticism of the plants referred to might have been made. His purpose in omitting them had been to encourage discussion, but his own views of the points to be considered when investigating the merits of any particular installation might be stated briefly as follows :

1. Straight route of product and convenience of despatch.
2. Maximum yield of saleable product.
3. Low power and fuel costs.
4. Possibility of continuous operation at full production.
5. No limitation of output imposed by the human element.
6. Scope for ready application to changed processes and conditions.

If those broad principles were applied to the various plants illustrated, it would readily be seen how nearly those plants approached the ideal. As regarded engineering refinement, that could only be defined as such when superfluous features and finish were introduced, and he did not think that British designers had transgressed unduly in that direction. He could claim to have been associated with the design of many of the new plants installed in the United Kingdom, and was in a position to state with conviction that the provisions arranged for more scientific lubrication alone had proved of enormous benefit.

He regretted that Mr. J. R. George's written contribution to the discussion had not been received in time for reading at the meeting, as the economic considerations involved were of the utmost importance, and many members present were more qualified to discuss such matters than he (Mr. Hand) felt himself to be. The tendency of recent years, however, had been in the direction which Mr. George outlined, and it seemed more than probable that that policy would be continued.

Indirectly attention had been drawn by Mr. Mackenzie to the limitations of the steam-engine drive as compared with a reversing motor for mill driving. Leaving out of consideration Case No. 2 in Table I., which referred to a reconstructed mill temporarily operated by an existing steam-engine, it should be mentioned that the varying torque characteristic of a steam-engine generally imposed some limit on the designer, inasmuch as the period of minimum torque had to be considered in relation to resistance of the mill, and the maximum torque obtainable with engine cranks in most favourable position, of course, greatly exceeded the minimum effort. That no doubt explained the tendency to keep engine dimensions within moderate proportions. The reversing motor, however, with its uniform torque permitted of more generous consideration, and it was usual to provide very ample reserve for dealing with future contingencies. The same reasoning might be advanced concerning the three-high plate mills scheduled in Table III. In each case peak load had been calculated as the total

power available over the period of rolling a plate of average length, and the advantage shown in the case of the motor-driven mills resulted from the greater energy obtainable from high-speed flywheels such as were used with the motor drive. He personally had studied Mr. Mackenzie's further remarks with great interest, and thought members would agree that opinions based on such ripe experience constituted a very valuable contribution to the discussion of the paper.

Some very outspoken comments were made by Mr. Mather with which he (Mr. Hand) was mostly in agreement. The question of reheating referred to was of considerable interest, as the present tendency in the United Kingdom was in the direction of reheating all blooms rolled into sectional material. If the lay-out of the Bethlehem Co.'s Steelton plant, Fig. 13, were referred to, it would be observed that blooms were charged and drawn from the reheating furnace at opposite sides. That expedited handling considerably, as the figures given concerning output would indicate. On the other hand, as Mr. Mather had suggested, it appeared quite practicable still further to develop continuous furnaces for that duty. In fact, as was well known, such furnaces were used exclusively by the Morgan Construction Company on all their merchant mills producing light structural material. He was particularly interested to learn that sleeper plate had already been rolled in India on a continuous mill, as that again emphasised a condition which had frequently been brought to his notice—namely, the possibility of successfully overcoming so-called difficulties when no handicap was imposed by traditional objections. He agreed with Mr. Mather as to the necessity of careful adjustment when rolling certain products on the continuous principle, but those adjustments could be very readily effected, and with no more than ordinary care on the part of the roller, it was certainly possible to produce enormous tonnages on such mills well within all usual commercial tolerance.

Several questions of considerable interest had been raised by Mr. Scarf. His remark concerning the somewhat brief reference in the paper to small rolling-mills of more usual type was not surprising, and he (Mr. Hand) only wished that he could have referred more favourably to that class of mill. The gulf between the best small merchant mills of ordinary type with which he was familiar and those of the "Morgan" type was enormous, and he could only repeat that in his judgment the small mill had been woefully neglected in development in Great Britain. He was not referring in particular to the mill trains and driving equipment, but to the entire lack of auxiliary equipment for dealing with large tonnages, the number of mills equipped with any form of mechanical cooling bank being surprisingly small. He was pleased that Mr. Scarf had taken up the question of conversion cost, as that was an aspect he had wished to deal with more fully, but had not met with much encouragement, manufacturers in general being averse to discussing publicly matters relating to costs. The position was rather different in America, where comparisons between various types of mill

plant were usually made on realised conversion costs. He thought the great difference in operating costs between British and foreign mills referred to by Mr. Scarf could be due only to the use of more suitable plant for the product in question, and greater efficiency allround. Considering one aspect only, that of yield, the saving in crop ends on the continuous billet and sheet bar mill was very considerable. He had turned up certain figures relating to an American mill which would probably be of some interest; its production of about 5000 tons per week being more comparable with what we were accustomed to in that country. It should be noted, however, that those figures related to the period of inflated values which obtained some few years ago, and would therefore be somewhat less at the present time. The total conversion cost, in that instance, from ingot to sheet bar and billet, including waste, loading, and every charge under control of the mill management, was less than 17s. per ton. Taking those figures, and lower wage rates and other costs obtaining in the United Kingdom into consideration, it should be possible to convert ingots to billets and sheet bars well within the figure of 15s. per ton mentioned by Mr. Scarf. He could not altogether agree with Mr. Scarf concerning the alleged disadvantages of the continuous mill. Admittedly the capital cost was high, but so was the mill production, and the wear and tear was no greater in proportion; in fact, generally less than the ordinary type of jobbing mill on which the whole train would be driven through one set of pinions, as compared with a number of pinion stands through which the total rolling load was distributed on a continuous mill. In the latest types of semi-continuous mills, the range of product was being considerably widened, and as regarded the technical skill required in the management of such mills, surely Great Britain in particular was well qualified. The "tonnage factor" mentioned by Mr. Scarf was the all-important consideration in that type of mill, and if that were used as the divisor, investment and labour cost appeared far more attractive than Mr. Scarf had suggested. He thought Mr. Scarf's statement concerning mill labour was somewhat misleading, as the number of men employed on some particular section of a mill plant gave little indication of operating costs. What really counted was the total number of hands comprising the entire labour force of the mill, from the receipt of raw material to despatch of rolled product, and in all cases which had been cited in the paper that applied. Personally, he rather admired the watchful attitude of the operators around most continuous mills, as that not only showed interest in the work, but more important still, indicated that the machine was setting the pace. Probably the strongest evidence which he could produce in support of his reasoning were the statements which Mr. Whitehead made concerning the performance of his Newport mill. If that mill could operate economically under the conditions outlined by Mr. Whitehead, surely Mr. Scarf would admit that at least one good case had been established for the continuous mill.

Certain observations respecting different types of plate mills had been made by Mr. West which, being based upon responsible control of such plant, could certainly be accepted as opinions of value. He (Mr. Hand) agreed that direct comparison was a little difficult, but it was of interest to note that the attitude of manufacturers towards the use of three-high plate mills in the United Kingdom was becoming increasingly favourable. As a matter of fact,^f he had heard nothing but praise for those mills from such firms as were now using them. As Mr. West remarked, the possibility of changing the middle roll speedily was an important advantage, with which might be coupled quick rolling and reduced power consumption due to its relatively small diameter.

Iron and Steel Institute.

FLAKES OR HAIR-CRACKS IN CHROMIUM STEEL, WITH A DISCUSSION ON SHATTERED ZONES AND TRANSVERSE FISSURES IN RAILS.

By AXEL HULTGREN, MET.ENG. (GOTHENBURG).

A DEFECT known as *snow-flakes* or *flakes* (America), *hair-cracks* or *hair-lines* (Great Britain), *Flocken* (Germany), and *cassures ligneuses* (France), has received much attention among manufacturers and inspectors of alloy steel forgings, particularly during the war. This defect has the appearance of approximately circular, bright, coarsely crystalline spots of varying size (from 2 to 20 millimetres), which may be seen in the fine-grained fracture of the heat-treated forging. It may also appear as lines without appreciable width on machined or polished surfaces.

Most of the literature existing on this subject was published in America in 1919 and 1920. From these publications it may be gathered that flakes—the defect will be so termed in the present paper—were at times the cause of serious rejections in that country. A similar statement referring to aircraft drop forgings, manufactured in Great Britain during the war, is made by Aitchison.⁽¹³⁾

PREVIOUS LITERATURE CONCERNING FLAKES.

An abbreviated review of previous literature on flakes, which has come to the author's notice, is given in Table I. The reference numbers in column 2 refer to the list of publications at the end of the present paper.

From an examination of Table I. it appears that flakes have been observed mainly in alloy steels, such as nickel, nickel chromium, chromium, and tungsten steels, but were also found in carbon steel. With few exceptions, flakes are considered to be actual cracks. In regard to the cause, or predominant cause, of flakes various opinions have been expressed, involving raw
1925—i.

TABLE I.—*Review of Previous*

Authority.	Reference.	Kind of Steel in which Flakes occur.	Nature and Appearance of Flakes.
Clayton, Foley, and Laney	1	Gun forgings of basic electric or basic open- hearth steel. C = 0.38, Ni = 2.9.	Generally not cracks but areas of weakness. In some cases cracks.
Rawdon .	2	Nickel steel. C = 0.40, Ni = 3.5. Nickel chromium steel.	Coarsely crystalline dis- continuities. Their faces have the appearance of crystals that were squeezed together while soft and plastic. Corners and edges are rounded and smooth. Surfaces have fine matt finish.
McKinney .	3	Steels made by acid and basic open-hearth, basic electric, and other processes. Probably almost equally preva- lent in carbon steel.	...
Mathews .	3	Nickel chromium steel. C = 0.40, Ni = 3.00 Cr = 0.80.	...
Knight .	3	Nickel steel.	...
Stevenson .	3	Nickel steel.	...
Unger .	3	Chromium steel. Nickel steel. Carbon steel.	...
Traphagen.	3	Alloy steels. Carbon steel.	...
Giolitti .	3, 4	Tender alloy steels.	Intercrystalline cracks.
Styri	5	Nickel steel.	Almost always associated with slag inclusions.
	9	High-carbon chromium steel.	Cracks.

Literature on Flakes.

Stage of Manufacture where Flakes Form. Mechanism of Formation.	Cause of Flakes (or Prevention of Flakes).	Remarks.
Overheating before forging causes carbon-rich areas to pass solidus, after solidification constituting weak areas.	Non-uniformity of carbon content, due to slow diffusion. Overheating.	...
Originate in the ingot as inter-crystalline shrinkage cracks along with the slag inclusions between the branches of the dendritic crystals.	Unsuitable size of ingot, design of mould, rate of cooling, and distribution of cooling stresses in ingot.	...
...	Improper temperature of pouring.	...
May occur after completion of hot-working, constituting a series of internal bursts. The flakes found did not start from cavities in the ingot, because they would then be striated in the direction of working, more like "silver streaks."	Excessive casting temperature. Excessive rolling or forging temperature.	Can be welded together by forging.
Probably not in forging (radial arrangement). Produced flakes by heat treatment without forging, rapid heating to hardening temperature, quenching in water, rapid heating to 650° C., rapid cooling.	...	Can be removed by forging.
...	No flakes occurred until nickel-steel turnings were introduced into the charge.	...
...	Incorrect forging practice. Not improper shape or size of ingot, or method of casting.	...
...	Presence of higher oxides of iron, due to turnings or too much ore in the charge.	...
Not present as cracks in the ingot. Flakes start in ferrite areas formed by decarburisation from the influence of inclusions of oxidising nature.	Formation of flakes is prevented by careful steel furnace practice, casting, soaking, reheating, forging, and heat-treating.	...
Form in the ingot or in the subsequent heating and forging, not in heat-treating.	Predominant cause: slag inclusions.	Styri here uses the term flakes collectively for various defects seen in the fracture.
During rolling, not during heat treatment.	...	

TABLE I.

Authority.	Reference.	Kind of Steel in which Flakes occur.	Nature and Appearance of Flakes.
Barba .	10	Gun steel forgings.	...
Hayward .	6	Nickel steel gun forgings.	...
Miller .	8	...	Films of oxide or other foreign matter in the grain boundaries.
Priestley .	10, 11, 12	...	Inclusions in centre of flakes when present in acid and basic open-hearth steel, but no inclusions in flakes when in electric steel.
Harbrecht .	12	...	No inclusions found in the flakes, but sometimes a small dotted line of inclusions along the outside of the flake.
Aitchison .	13	Aircraft drop forging steels.	In some cases non-metallic impurities, in some contraction cracks and cavities.
Sommer and Rapatz	14	Also found in hard chromium and tungsten steels of not too high chromium and tungsten content.	...
Rapatz .	15		
Schleicher .	16	Nickel chromium steels. C = 0.25-0.40 Ni = 3.20-3.70 Cr = 0.35-0.70 Mn = 0.60-0.75	In steels with flakes oxide inclusions were found, which were reducible in hydrogen at 940° to 950° C.

(continued).

Stage of Manufacture where Flakes Form. Mechanism of Formation.	Cause of Flakes (or Prevention of Flakes).	Remarks.
...	Melting and ingot practice on well-known sound principles avoids practically all of the difficulty. ...	...
In cooling of the ingot or during forging.	...	By gradually diminishing the nickel content from 3 to 1 per cent., finally to 0, improvement was obtained, until flakes finally disappeared. ...
...
...	Bottom pouring gave rise to flakes, probably due to high pouring temperature. Further causes: sudden cooling of ingot or cooling down entirely after casting. Present practice: strip ingot early, heat immediately for forging; transfer forging to annealing furnace before it cools much below critical point. ...	...
...
In the ingot after solidification, not in drop forging or heat treatment.	No known method of cure nor of prevention. Satisfactory casting arrangements diminish materially the number of hair-cracks.	...
...	Caused by separation of ferrite, occasioned by an alteration in the iron-carbon equilibrium diagram, due to deoxidation products remaining in the steel. ...	...
...

materials, melting practice, casting and pouring practice, shape and size of ingots, cooling of ingots, heating for forging or rolling, hot-working practice, cooling after hot-working, and heat-treatment practice. In the opinion of many authorities flakes are the result of several factors combined.

EXPERIENCE OF FLAKES AT THE GOTHENBURG WORKS OF AKTIEBOLAGET SVENSKA KULLAGERFABRIKEN.

A defect in every way similar to the one described has been noticed from time to time in the manufacture of ball and roller bearings at the works of Aktiebolaget Svenska Kullagerfabriken (SKF) in Gothenburg. The steel used has the following composition :

C	=	1.0		per cent.
Cr	=	1.5		"
Mn	=	0.25	-	0.35 "
Si	=	0.25	-	0.35 "
P	=	less than 0.025 per cent., generally 0.012 - 0.017 per cent.		
S	=	"	"	0.020 " " 0.010 - 0.015 "

Flakes have been found in forged rings of larger sizes, about 400 millimetres outer diameter and upwards, and in heavy rolled or forged bars above 60 millimetres in diameter. Obviously objects of larger section are more susceptible to flakes than smaller ones.

The main part of the bars and forgings was made at the Hofors Steelworks in acid open-hearth furnaces, but the same defect has also occurred in steel delivered by three other Swedish steelworks, in all cases acid open-hearth steel of the composition given above.

The flakes were observed :

1. In the fractures of hardened discs, cut from bars for inspection of the quality of the steel, this being a regular operation before the bars are accepted.
2. In the fractures of ball and roller bearing rings that broke in hardening. These rings were made partly from large forgings, and partly trepanned from solid bars of sizes mentioned above.
3. In similar rings that were for some reason broken after hardening.

The rings and discs were hardened in water. For a special purpose large rings have been made from a steel of the composition :

C	=	0.70	per cent.
Cr	=	1.0	„
Mn	=	1.0	„

in this case the rings being hardened in oil. Some of these rings also cracked in hardening, showing flakes in the fracture.

In all cases the flakes have been easy to recognise as such on account of their bright, coarsely crystalline appearance, contrasting with the surrounding silky fracture of the hardened steel. Examples are shown in Figs. 6 and 7 (Plate XIV.). The flake areas are generally roughly circular, of a size varying from about 2 to 20 millimetres. When present in large rings machined from ring forgings, they were found somewhere in the central zone of the section. In the case of outer and inner rings being trepanned from solid bar, flakes were found in inner rings only. In that case it might happen that the flakes extended to the surface of the ring, hence oxidation during heating was made possible. As a result, the flake in the fracture might appear as a black area. For these and other reasons it was considered that flakes were actual cracks existing before heating for hardening. The plane of the flake was always found to be parallel with the geometrical axis of the bar or ring, the orientation being usually approximately radial.

Although flakes had been encountered occasionally since 1918, the quantity of defective material was small, and considered to be of minor significance. During the years 1923 and 1924, however, the manufacture of roller bearings developed to larger sizes than previously used. As the size of rings increased, flakes became more frequent. On one occasion, out of a lot of eleven rings $762 \times 678 \times 114$ millimetres, six broke in hardening, all the fractures showing flakes. The situation was serious, the more so since no method was known of detecting flakes without destroying the rings. Consequently, the necessity arose for investigating the flake question more thoroughly.

EXPERIENCE OF FLAKES AT THE HOFORS STEELWORKS.

The following data were kindly placed at the author's disposal by Mr. Albert Olsson, chief metallurgist of the Hofors Steelworks.

In 1918 round bars of larger sizes—64 to 125 millimetres diameter—were rolled of chromium steel for ball-bearings of the composition given above. At first, bars over 85 millimetres diameter were rolled direct from ingots, bars under 85 millimetres diameter being rolled from reheated billets. In these bars flakes occurred to a great extent, particularly in sizes over 85 millimetres diameter. Some flakes were also found, however, in the 64-millimetre bars. At the time the conclusion drawn was that direct rolling was responsible for the trouble. Accordingly, it was decided to roll bars of all sizes from reheated billets.

In 1921, after it had become apparent that flakes still occurred in rolled bars, various experiments were made in order to study this defect. The main results of these experiments were :

1. Repeated attempts to find any relation between variation in melting practice—as seen in furnace records and from the analysis of the respective heats—and variation in number of flakes in bars rolled from these heats, failed to establish any such relation.
2. Reheating alone without mechanical work did not remove flakes.
3. Discs hot-sawn from a bar after leaving the rolls did not contain flakes, although flakes might be present in the bar.
4. Flakes in 117×117 millimetre billets could be removed by rolling to 100×100 millimetres ; sometimes even rolling to 110×110 millimetres was sufficient.
5. Discs cut from annealed bars, after hardening and fracturing, might show flakes of the appearance illustrated in Fig. 1, giving the impression that the flakes had been closed near the machined surface by the action of the cutting-off tool. When, however, the discs were carefully filed after cutting off, flakes were found that extended to the edge of the fracture.*

In 1922 a consignment of 150 bars, 82.5 millimetres and 87.5 millimetres round, was rolled from reheated billets. The

* The explanation of this phenomenon may be : (1) Either distortion of the flake plane next to the machined surface ; (2) or pressing together of the flake faces in this part, and subsequent welding in heating ; (3) or both.

bars were tested as usual by disc inspection, 10-millimetre discs being cut off close to the hot-sawn ends of the bars. Only a few discs contained flakes, but it was decided to make further tests by taking discs 150 millimetres from the ends of the bars. All these discs showed flakes, with very few exceptions.

In rolling new bars to replace the rejected ones, ingots from seven open-hearth heats, representing various temperature conditions in the furnace, were used. The ingots were reheated very carefully, the final temperature being somewhat higher than was ordinarily the case. Out of the 150 bars rolled, 44 contained flakes, but all of them were located within a central circle of 15 millimetres radius. Thus it was possible to pass the bars as good for making ball-bearing rings. It was concluded that careful

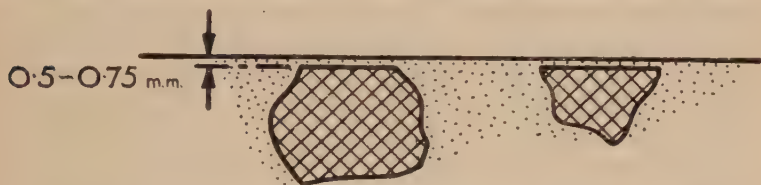


FIG. 1.—Sketch of Disc Fracture with Flakes not reaching the Edge.

reheating tended to cause flakes not to appear, or, if they did, to be displaced towards the centre of the rolled bars. As to the mechanism of their formation, it was thought that, during the successive stages of the rolling, cracks formed as a result of the deformation stresses. These cracks were supposed to be continuously welded together in subsequent passes, at the same time new ones being formed. The flakes found in the finished bar would then have been formed in the last pass, or the last passes.

As a consequence of the investigations made, heavy bars were, from that time on, forged from rolled billets. It was first believed that the flakes were got rid of in this way, but it was soon found that they still occurred, although perhaps not to the extent previously experienced in rolled bars.

PLANNING THE PRESENT INVESTIGATION.

In planning this investigation little guidance could be derived from the previous literature on the subject, too many conflicting

opinions having been expressed. The quality of the steel has been repeatedly made responsible for the formation of flakes. For this reason the following data may be of interest.

The steel here considered is made from very pure Swedish raw materials. The open-hearth charge is made up exclusively of charcoal pig iron and chromium steel scrap of the firm's own manufacture, including oily turnings, the latter up to 10 per cent. of the total charge. The furnace capacity is 15 tons; the ingots, weighing 560 kilogrammes, are top poured, with feeding-box, 12 inches square at the top, big end up. Apart from routine microscopical examination, constantly employed, the quality of the steel has been and is repeatedly tested by endurance tests on ball-bearings, carried out in the Gothenburg Laboratory. In these tests the Hofors chromium steel has invariably given good results. As to the amount of slag inclusions, it is the author's impression, from many years of microscopical examination, that the general run of Hofors steel is among the purest of this class. Sulphide inclusions are present, of course, alumina inclusions as well, but both in small quantities; glassy and dark, rolled-out slag inclusions are practically absent in this steel. Consequently, the quality of the steel, as demonstrated in service and by microscopical examination, is good. This is of interest, because it is known that certain other manufacturers of ball-bearing steel have for years had no trouble with flakes.

Further, in microscopical examination of specimens containing flakes, on several occasions, it has not been possible to establish any connection between the presence of flakes and any unusual amount of inclusions, nor to trace the actual line of a flake, as seen in the section, through any large group of inclusions. The flake may be found to pass through a group of inclusions, but the latter were never found to be prominent.

In trying to solve the flake problem, it appeared to be of primary importance to ascertain at what stage in the sequence of manufacture the cracks form. Rawdon concludes ⁽²⁾ that the defect has its origin early in the history of the metal. The present author, however, and, as stated above, Mr. Olsson as well, from observations made formed an opposite conception. If flakes started as cracks in the ingot, it did not seem plausible, whatever shape they might have had originally, that,

after the deformation in rolling or forging, the flakes would be roughly circular, as was actually found in the chromium steel bars and rings. Furthermore, Rawdon's opinion could not be reconciled with the fact found at Hofors, and also stated by Mathews and others, that slight hot-working was sufficient to weld flakes together completely.

Accordingly, the present investigation was started—in July 1924—on the hypothesis that the flakes formed during the last hot-working operation.

THE PRESENT INVESTIGATION.

Test Series 1.—Distribution of Flakes in Sections of Billets.

On previous occasions, when flakes had been found in rolled billets of "Gothic" or square section, it was noted that they were often roughly parallel to one of the diagonals of the section. In order to study this further, fourteen billets, 95 millimetres square, were annealed, and 10-millimetre discs were cut off from both ends clear of the part deformed in shearing. For the detection of flakes the following procedure was adopted.

The discs, which are ground on emery-paper on one side, are placed with this side up on the poles of an electro-magnet, in such a way that the lines of force traverse the central part of the section. The whole is arranged in a tilted position, the inclination of the section to be examined being about 15° to the horizontal. A suspension of very fine steel grindings in gasolene is slowly poured on to the top part of the specimen. In streaming down the steel surface the steel dust collects on all cracks present, except on those that run parallel with the lines of force. By turning the disc into various positions and repeating the test, a position is usually found in which all cracks present are revealed, or else the absence of cracks is proved. A similar method has been described by Rawdon.⁽²²⁾

Of the fourteen billets examined in this way three showed flakes in both ends; seven showed flakes in one end, but were free from flakes in the other; four were free from flakes in both ends.

Of the thirteen discs containing flakes ten had all the flakes present arranged roughly parallel to the diagonal direction of

pressure in the last pass through the rolls. This direction could

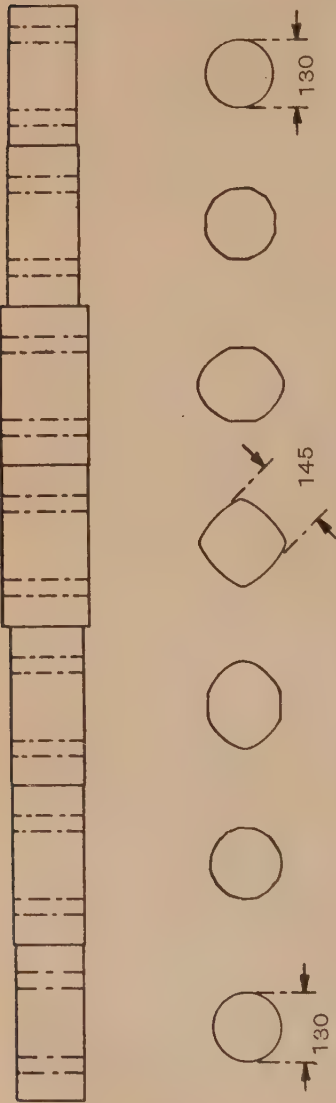


FIG. 2.—Sketch of Experimental Bar Forging.

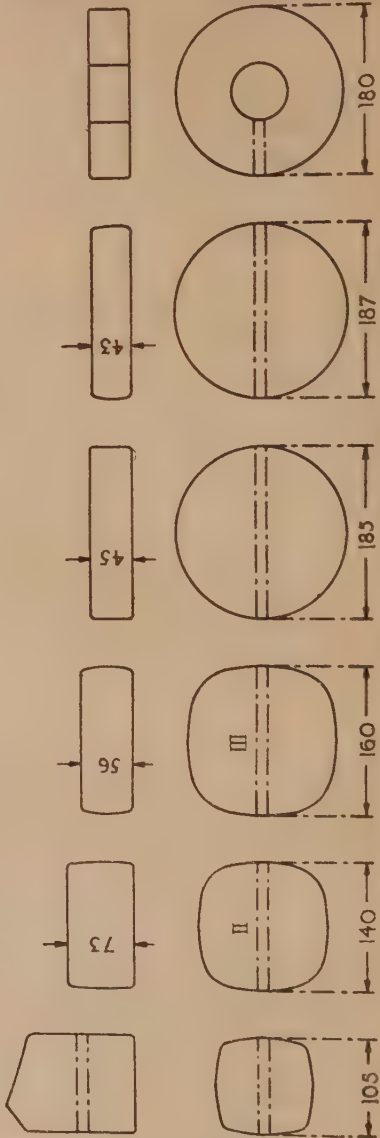


FIG. 3.—Successive Steps of Forging 180-Millimetre Ring in Eccentric Press.

be ascertained from the shape of the section ; two showed flakes parallel to both diagonals of the section ; one showed flakes

parallel to one side of the section only. Two of these specimens are shown in Figs. 9A and 9B (Plate XV.). From this series it was concluded tentatively that during rolling, in the last pass or the last two passes, the secondary tension, set up in the billet in consequence of the lateral spread, caused the interior to split up, the cracks following the vertical diagonal.

Test Series 2.—Forging 130-Millimetre Round Bar from Billet.

A billet 145 millimetres square was first forged in successive steps to 130 millimetres round in one end. Then the other end was forged in the same way, the first direction of forging being at right angles to that of the other end. The manner of forging is illustrated in Fig. 2. The bar was then annealed, and two discs were cut from each stage of forging.

On examining the discs in the manner described above, flakes were found to be present in the centre of the billet, of approximately diagonal orientation. The flakes seemed to disappear gradually during forging. It could not be stated with certainty whether any new flakes formed meanwhile. The net result was that the finished bar contained small flakes in the centre of one end, whereas flakes were absent in the other.

Test Series 3.—Forging Medium Size Rings by Upsetting in Eccentric Press.

In Fig. 3 are illustrated the successive steps of forging a ring 180 millimetres in outer diameter and 43 millimetres thick, from a blank sheared off from a 105-millimetre square billet. From each stage axial sections were taken, from different blanks naturally, and examined for flakes. A cross-section of the billet was also examined. Of these sections only II. and III. showed flakes, the others were free from flakes. The distribution of the flakes was approximately parallel to the direction of the upsetting force.

Test Series 4.—Forging Large Rings on Mandrel.

For reasons given already, it was above all desirable to get rid of flakes in large ring forgings. A number of experiments

in forging large rings was therefore made. The following ring dimensions were selected :

	Millimetres.
Outer diameter	= 750
Inner diameter	= 640
Thickness	= 55
Width	= 125

As seen below, these dimensions were not, however, strictly adhered to—a fact that has probably not been without influence on the results obtained.

The rings were forged under a 2-ton steam-hammer from ingot sections. The sequence of forging operations was as follows :

1. An almost cubical blank was cut from the ingot, the latter measuring 10×10 inches at the bottom, 12×12 inches at the top.
2. The blank was upset and hammered to a cake of 123 millimetres height ; a hole pierced with a tapered

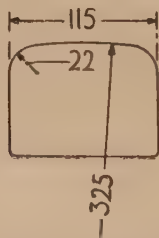


FIG. 4.—Section of Forging Mandrel.

95-millimetre plug ; the hole widened by driving a 110-millimetre tapered plug through it. The dimensions after these operations were $415 \times 110 \times 125$ millimetres.

3. Forging on mandrel of 110 millimetres diameter to $465 \times 255 \times 125$ millimetres.
4. Forging on mandrel shown in Fig. 4 to $650 \times 510 \times 125$ millimetres.
5. Finishing to $750 \times 640 \times 125$ millimetres.

Before each forging operation the blank was reheated. For measuring the temperature a Wedge pyrometer was used. The accuracy of this instrument did not seem to be very great ; the readings were particularly affected by the distance from the

observer to the object viewed. The reheating temperature designated below as normal was measured from approximately 1025° to 1050° C., the one termed high from 1050° to 1150° C., and the one termed low from 950° to 1025° C. During each forging operation the temperature as measured fell normally to 700° – 850° C.

Ingots from a single open-hearth heat were selected for this series and numbered 1, 2, 3, &c. The bottom blanks were designated A, the middle blanks B, and the top blanks C. The latter were free from pipe.

During these experiments the following factors were intentionally varied :

1. Position of blank in ingot.
2. Initial temperature of forging.
3. Finishing temperature of forging.
4. In one case the cubical blank was forged repeatedly in all three directions before upsetting.
5. Power of blows, particularly towards finishing.
6. In one case the hole was pierced from the side of the ingot.
7. Width of mandrel.

After forging, the rings were cooled down on the floor, then annealed at 790° C., allowed to cool, hardened in water from 810° C., and finally broken into at least eight pieces under the hammer. All fractures were examined for flakes. Some of the pieces were afterwards annealed and sectioned, the sections being examined for flakes by the magnetic method. The main results are given in Table II.

As seen from Table II., some tests were made in duplicate, *i.e.* under the same conditions as far as they could be controlled. The results in such cases often do not agree. Most of the rings contained flakes. Although some did not, there is no single condition, of those studied, that has given consistently good results, except possibly reduction in width of section.

In this state of affairs the matter was reconsidered. Obviously, the conflicting character of the results obtained up to this point indicated that the factor constituting the real, or perhaps the predominant, cause of flakes had not yet been put to the test. The hypothesis followed, that flakes formed in the final hot-working

TABLE II.—*Forging of Large Rings.*

Designation of Blank.	Reheating Temperature in each Operation.	Finishing Temperature in each Operation.	Manner of Forging.	Section of Ring. Millimetres.	Appearance of Fractures.
1 A	Normal	Normal	Normal	125 × 53	Many small flakes
1 B	Normal	Normal	Normal	128 × 50	Many small flakes
1 C	Normal	Normal	Normal	127 × 57	Several very small flakes
2 A	Low	Low	Normal	125 × 58	Most fractures without, a few with many very small flakes
2 B	Low	Low	Normal	130 × 54	Only one small flake observed
3 A	High	High	Normal	130 × 53	A few flakes in two fractures only
3 B	High	High	Normal	125 × 51	A few flakes in several fractures
5 A	Normal	Normal	Blank forged in all three directions before up-setting	128 × 51	Few or many flakes in all fractures, mostly of average size
6 A	Normal	Normal	After piercing, heavy blows	125 × 50	Numerous large flakes (up to 10 millimetres) in all fractures
7 A	Normal	Normal	After piercing, light blows	122 × 55	No flakes
8 A	Last operation—high temperature		Normal	125 × 52	Many flakes in all fractures
6 B	Normal	Normal	After piercing, light blows	127 × 57	No flakes
7 B	Normal	Normal	After piercing, heavy blows	117 × 58	No flakes
5 B	Normal	Normal	Light blows in last operation	120 × 60	No flakes
4 A	Normal	Normal	Heavy blows throughout	125 × 58	Separate small flakes
4 B	Normal	Normal	Light blows in last operation	122 × 58	Separate small flakes
4 C	Normal	Normal	Heavy blows throughout	115 × 55	Some fractures with some flakes
8 B	Normal	Normal	After piercing, light blows	129 × 52	Many flakes
2 C	Normal	Normal	$\frac{1}{2}$ ring light blows	129 × 52	Many flakes
			$\frac{1}{2}$ ring heavy blows	129 × 48	Most fractures free from flakes
7 C	Normal	Normal	Pierced from the side of the ingot	107 × 62	No flakes
5 C	Normal	Normal	Normal	105 × 75	No flakes
8 C	Normal	Normal	Last mandrel 140 millimetres wide	115 × 63	Many small flakes

Width reduced

operation, did not appear to be correct. The conclusion that the determining factor, after all, was to be sought for "early in the history of the metal" was close at hand, but nevertheless was rejected, for the reason that all evidence regarding the distribution of flakes, as it accumulated, led more and more to the opposite view. In Plate XVI. are shown central sections parallel to the sides of the ring taken from annealed ring fragments, and treated by the magnetic method. It is seen that most of the cracks were approximately radial. Some cracks had a definite orientation to the flats and impressions formed on the outer and inner ring surface during the final forging operation. From this the idea of a close connection between this operation and the formation of flakes was strengthened.

During all the experiments made up to this point one factor was consistently neglected, viz. the rate of cooling after forging. This was tested in the following series.

*Test Series 5.—Continued Tests with Large Ring Forgings.
Different Rates of Cooling.*

All rings were forged in the ordinary way, the heating also being normal. Forgings *b* and *c* were taken from the same ingot, and forged alternately on the same occasion, the same applying to *d* and *e*. The latter rings were made of larger section, the outer diameter being kept the same as before. Rings *a*, *b*, *c*, and *d*, immediately after forging, were laid on the floor and covered with charcoal dust.* Ring *e* was allowed to cool on the floor without any cover. The results are given in Table III.

TABLE III.

Mark.	Section. Millimetres.	Cooling Conditions.	Results.
<i>a</i>	120 × 55	Covered with charcoal dust	No flakes
<i>b</i>	120 × 55	Covered with charcoal dust	No flakes
<i>c</i>	120 × 55	Covered with charcoal dust	No flakes
<i>d</i>	130 × 63	Covered with charcoal dust	No flakes
<i>e</i>	130 × 63	Cooled on the floor without cover	Broke in hardening, through flakes. Numerous flakes in all fractures

* There is plenty of charcoal dust in Swedish ironworks.

The fracture of ring *e* is shown in Fig. 11 (Plate XVII.).

It was inferred that the flakes form during cooling after forging, and that they can be prevented by retarding the rate of cooling. In order to confirm these conclusions it was considered unnecessary to spend more time and money on expensive large forgings. Further tests were therefore made on bars.

Test Series 6.—Local Forging. Rapid Blows.

One 5-inch square billet was in one heating forged down locally at both ends, as illustrated by Fig. 5. The blows were

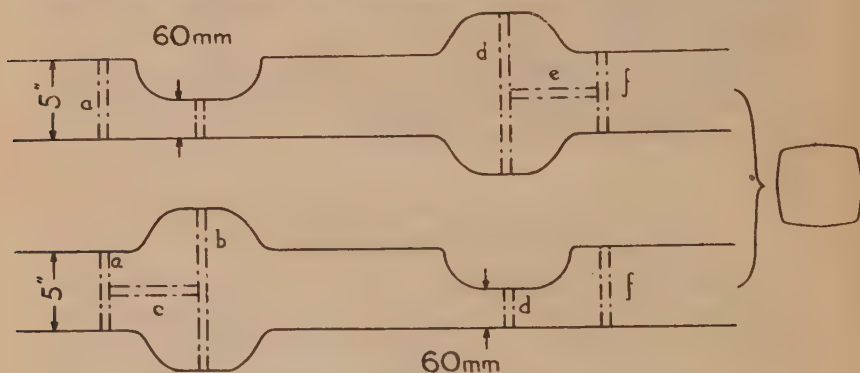


FIG. 5.—Sketch showing Manner of Local Forging of Billet.

applied as fast as the hammer would work. The billet was then left to cool in the air. After annealing, slabs were taken out as indicated in the figure and examined for flakes. Flakes were found in the slabs *b* and *d* in the central portion, lying parallel to the flat surface. The other slabs were free from flakes. The direction of the flakes in this case is unusual, but may be explained tentatively as follows. The thin, forged-down part of the billet cooled faster than the adjacent parts of heavier section. The contraction of the former during cooling was therefore to some extent resisted by the latter, tension being set up at right angles to the forged surface, thus giving rise to cracks parallel to the surface.

Six other 5-inch square billets were forged in a similar way, one end being heated to a high temperature, the other rather cold.

In addition, the end forged last, either hot or cold, was buried in charcoal dust after forging. In this way four different combinations of conditions were tested. After annealing, slabs were taken as described. All were free from flakes. It is probable that, due to the cover, which extended over the greater part of the billet, the cooling of the uncovered end was sufficiently retarded to prevent the formation of flakes.

Test Series 7.—Forging 160-Millimetre Bars. One End Cooled in Air, the Other Buried.

Three 160-millimetre round bars were forged from 8-inch square billets. After reheating and forging one end, the other end was placed in the furnace, the first end cooling in the air meanwhile. Finally, the second end was forged, and allowed to cool under a cover of charcoal dust. After annealing, two discs were cut from each end of each bar. One of them was hardened and fractured, the other examined by the magnet test. The results are given in Table IV.

TABLE IV.

Bar No.	Hardened and Fractured Discs.		Magnetic Test.	
	Air-Cooled End.	Buried End.	Air-Cooled End.	Buried End.
1	Numerous flakes	No flakes	Flakes	No flakes
2	No flakes	No flakes	No flakes	No flakes
3	Numerous flakes	No flakes	Flakes	No flakes

The effect of retarded cooling in preventing the formation of flakes is obvious.

Test Series 8.—Rolling Billets at Normal and Low Temperature. Various Rates of Cooling.

112- and 109-millimetre square billets were rolled from ingots. In the former case the ingot was reheated well as usual, in the latter to an extremely low temperature. From each bar, after it left the rolls, three adjacent hot-sawn billets were taken and used for the test. One was immediately buried in charcoal dust,

another put on a grate of iron bars to cool in the air, and the third was cooled by air-blast directed, back and forth, on to all parts of the surface. From one end of each billet, after annealing, two adjacent 10-millimetre discs were cut off, the outer one 20 millimetres from the hot-sawed end. Both discs were examined for flakes on the magnet. Brinell tests (10 millimetres, 3000 kilogrammes) were made on the central part of all inner discs. The results were as given in Table V.

TABLE V.—*Billets Rolled at Normal and Low Temperature. Different Rates of Cooling.*

Temperature of Rolling.	Manner of Cooling.	Outer Disc.	Inner Disc.	Brinell Number.	Remarks.
Normal	Buried	No flakes	No flakes	255	The flakes were distributed in an intermediate zone in various directions.
	In air	Several flakes	Numerous flakes	364	
	In air-blast	Numerous flakes	Several flakes	387	
Low	Buried	No flakes	No flakes	266	The flakes found were close to the centre, most of them parallel to the rolling pressure.
	In air	One flake	No flakes	340	
	In air-blast	One flake	Two flakes	351	

Slow cooling prevented formation of flakes. Cooling in air-blast did not seem to produce more flakes than cooling in still air. In the present case low reheating temperature was favourable, but further experiments are needed to settle this question, since previous experience at Hofors seems to point in the opposite direction.

Test Series 9.—Further Tests on Rolled Bars.

Out of one hundred 109×109 millimetre billets, thirty were cooled on the floor and seventy buried in charcoal dust. From each billet a thick disc was cut off with the oxy-acetylene flame. These discs were annealed, and thin discs cut out clear of the cut surface. The discs were hardened and fractured. Of the thirty air-cooled billets three showed flakes, all slowly cooled billets were free from flakes.

Out of twenty-one rolled bars 93 millimetres in diameter, eleven were cooled in air and ten buried in charcoal dust after rolling. Upon disc inspection, all of the former were found to contain flakes, whereas the latter were free from flakes.

FLAKES PRODUCED IN CUTTING WITH THE OXY-ACETYLENE FLAME.

When billets have had one end cut off with the oxy-acetylene flame, for seaminess or similar defect, it has been observed several times that the blank taken close to the cut end in forging is liable to develop cracks, and consequently has to be discarded. The explanation was furnished when a bar, 2 inches round, cut in this way, was tested by disc inspection after annealing. The disc, taken close to the cut end, was hardened and broken. The fracture showed two unmistakable flakes about 11×4 millimetres at a distance of 1.5 millimetre from the cut surface. One of these is seen in Fig. 8 (Plate XIV.). New discs taken from the bar showed no flakes.

MICROSCOPICAL EXAMINATION OF FLAKES.

The question whether flakes are inter- or intracrystalline has been discussed. Since such terms may refer to the dendrites of the ingot, which are deformed during hot-working, or to the actual crystal grains of austenite at high temperature, or of ferrite, pearlite, or sorbite at lower temperatures during forging and rolling operations, and subsequent coolings, it is obvious that they should not be used without qualification. That the flakes have no consistent orientation to the dendrites of the ingot in the cases here studied is clear from the close relation between the orientation of the flake planes, and the manner in which the final hot-working was carried out.

The flakes form during cooling after hot-working, at what stage the author has not yet been able to determine. From an analysis of cooling stresses, given later, it appears probable that the cracks are formed after the central portion has cooled down appreciably.

The microstructure of this steel after hot-working and cooling

in air is seen in Figs. 12 and 13 (Plate XVII.). The previous austenite grains are sometimes, but not always, separated by a thin network of cementite. Each austenite grain has transformed into a great number of grains or colonies of sorbite and lamellar pearlite. The dark lines are cracks, flakes. It is seen that their width is not measurable at this magnification ($\times 1000$). From these photographs it may be concluded that the cracks follow mainly the austenite grain boundaries, but sometimes deviate and pass arbitrarily through pearlite and sorbite grains.

The actual flake surface of a hardened specimen was examined, unetched, under the microscope at high magnification ($\times 1000$). Small round grains, undoubtedly cementite particles, were seen in relief; also a fine relief pattern, suggestive of grain boundaries and twinning, was observed.* This relief pattern probably accounts for the matt appearance of flake surfaces, as pointed out by Rawdon,⁽²⁾ as distinct from the bright appearance of a fresh crack. It should be remembered that from the time of their formation until the flakes are discovered the steel has generally been annealed and hardened, consequently has passed the following sequence of transformations: Acl, Ar1, Ac1, Ar".

INFLUENCE OF RETARDED COOLING OF CHROMIUM STEEL, AFTER ROLLING OR FORGING, ON THE MICROSTRUCTURE AND ON THE RESULT OF SUBSEQUENT ANNEALING.

When a rolled bar or forging of chromium steel, of the composition given, after hot-working, is cooled down freely in air, as is the ordinary practice, some pro-eutectoid cementite will separate out as a more or less continuous network in the grain boundaries of the austenite before the latter transforms into sorbite and lamellar pearlite. The structure obtained has been described already. The separation of cementite is, however, not complete, due to under-cooling, consequently the sorbitic and pearlitic matrix will have a carbon content in excess of the eutectoid composition. The result is that in annealing, after the maximum

* Compare *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1922, vol. lxxvii.: E. H. Hemingway and G. R. Ensminger, "Surface Changes of Carbon Steels Heated *in Vacuo*," p. 392; H. S. Rawdon and H. Scott, "Microstructure of Iron and Mild Steel at High Temperatures," p. 414.

temperature—about 790°C .—is reached, there will be distributed in the austenite matrix a great number of small cementite particles, representing the amount of carbon, previously in the sorbite, which is in excess over that which the austenite can dissolve at this temperature. The cementite network at this temperature is partly dissolved; part of it is left as separate particles in rows, at least after the temperature has been held for some time. In cooling down slowly, on account of the great number of nuclei of cementite, closely distributed, the conditions for forming a perfectly granular pearlite are very favourable. Hence a steel of this composition—carbon and chromium content—may be considered comparatively easy to anneal. This is so if the cooling after hot-working has been carried out as usual. If, however, after hot-working the steel be slowly cooled, the pro-eutectoid cementite has the opportunity to gather into a continuous network of broad veins. At the same time the carbon content of the matrix will be only slightly greater than the eutectoid composition. Consequently, the number of nuclei of free cementite present at the maximum annealing temperature is small; the pearlite formed during subsequent cooling will therefore have a tendency to become lamellar. In other words, in this case a slower cooling rate is required in annealing in order to obtain granular pearlitic structure. Further, the presence of a massive network of cementite necessitates prolonged holding at the maximum temperature in order to break it up.

PRESENT COOLING PRACTICE AT HOFORS.

From these considerations it was to be expected that retarded cooling after hot-working, introduced to prevent the formation of flakes in large bars and forgings, would cause difficulties in annealing. In fact, it has been found at Hofors that if the bars after rolling are buried immediately, the usual annealing practice for such steel will fail to produce the desired softness—less than 200 Brinell—and annealing structure. If, however, the bars are allowed to cool in the air down to an estimated temperature of about 750°C . and are then buried, the annealing result becomes normal, a hardness of about 180 Brinell, and a granular pearlitic structure being obtained. Furthermore, it has been found

unnecessary to cover the bars completely with charcoal dust. The present practice is to place first one layer of bars closely together, as they come from the mill, on a bed of ashes that forms part of the mill floor. On the first layer are then placed one or two additional layers, the ends only being protected from rapid cooling by contact with charcoal dust. Any cover on the top does not seem to be needed. This points to the conclusion that previous practice was so close to the permissible limit in the rate of cooling that minor variations only were sufficient to cause flakes to form or not to form.

For ring forgings the following practice is followed. Rings weighing more than 40 kilogrammes are placed on the earth floor of the forging shop and immediately covered with a layer of charcoal dust, not exceeding 1 inch. There is, in ring forging, no danger of finishing at so high a temperature that the structure is undesirably affected by the slow cooling in the manner explained above.

Since the introduction, in the beginning of November 1924, of retarded cooling after rolling and forging larger sizes of chromium steel, no flakes have been detected. From November 1924 up to the beginning of February 1925, 112 tons of rolled bars 75 to 113 millimetres diameter have been inspected.*

DISCUSSION OF RESULTS. MECHANISM OF FORMATION OF FLAKES.

The starting hypothesis, that flakes form during the final stage or stages of hot-working, was disproved by the results of the present investigation. The flakes form during cooling after hot-working. If the forging or bar be cooled down to ordinary temperature between two operations of hot-working, flakes may form. On further hot-working the flakes are usually welded together, and new ones may form during subsequent cooling.

From the fact established, that the formation of flakes is prevented by suitably retarding the rate of cooling after hot-working, it follows that the flakes are mainly due to the cooling stresses that develop as a result of the differential rate of cooling in the exterior and interior portions of the object.

* In introducing the paper, the author stated that up to the middle of April 540 tons of bars of those dimensions had been rolled and inspected with the same results.

The manner in which the last hot-working operation is performed has been found to affect the distribution of flakes formed. It is concluded, therefore, that the cooling stresses induced in the interior of the metal are superimposed upon remaining stresses from hot-working. At a given moment there will be at every point a resultant main stress of given direction and magnitude. During the course of cooling this stress will vary with the temperature, and so will also the cohesion of the metal. If at any time in some point in the mass of the steel the curve of varying stress intersects the curve of varying cohesion, a crack will start and spread instantaneously, probably at right angles to the resultant main stress, until the stress is sufficiently relieved. In this way the roughly plane shape of the flakes is explained, and also their regular distribution approximately at right angles to the internal tension induced in the last hot-working operation.

Howard,⁽²³⁾ in discussing the formation of so-called shattered zones in rails, tentatively suggests the explanation that they are caused by stresses developing during cooling after rolling, consequently the same conclusion as that formed by the author concerning flakes. This is discussed further below. Howard's analysis of these cooling stresses in their formation, change, and effects is so convincing and clear that the author can do no better than quote it here in full :

“ During cooling, internal strains are generally set up in cast, rolled, and forged shapes. At an early stage, when the interior metal is hotter than the peripheral, the latter is put temporarily into a state of tension, which changes to a state of compression when the interior has cooled. This reversal of internal strains accounts for the introduction finally of a force of the kind required to rupture the interior metal.

“ It is necessary to explain, or offer a conjectural reason, why the peripheral metal does not rupture, or escapes the tendency to do so when in a state of tension, although the interior metal is expected to do so under the same kind of strain. The peripheral metal when under tension is not restrained from radial contraction, therefore it can display the phenomenon of permanent elongation. On the other hand, the interior metal, after the cooling strains have reversed themselves, is exposed to tensile strains along each of its three axes, on account of the peripheral metal then being in compression. The phenomenon of permanent set or elongation

can hardly take place when the metal is strained in three directions. Stressed in such a manner it seems possible to effect the rupture of steel without the display of elongation other than elastic.

“There is no grade of steel known which possesses a very high tensile strength at rolling and forging temperatures, hence none could be expected to sustain without rupture a tensile stress of magnitude simultaneously received in three directions. The minimum strain necessary to cause rupture, in the absence of opportunity to display the phenomenon of elongation, must indeed be a very limited one, and cracks formed under such circumstances need not possess a measurable width of opening between opposite faces.”

It may be added * that the distribution of cooling stresses to a great extent depends upon the shape of the object. In a perfect sphere or cylinder the external metal would form, so to speak, a continuous arch unable to yield when subjected to pull from the interior during the later stage of cooling.

In a square or flat object, in this period, the sides will be forced to bulge inwards somewhat, thus causing some relief to the stresses. At that time, however, the peripheral metal may be fairly cold and rigid, consequently unable to yield enough permanently to prevent cracking in the interior. The author hopes by future experiments to study the cooling conditions in different points of a cooling object, and to ascertain the actual temperature at which the cracks form.

Experience has shown that the size of the object has great influence on the formation of flakes, larger objects being more susceptible to this defect. In large objects the maximum difference in temperature, which is reached between surface and interior during the cooling period, is greater than in small objects. Thus, in the first stage of cooling, a greater amount of permanent stretching is forced upon the peripheral metal from the still hot interior. In the second stage of cooling, after the stresses have reversed themselves, the tension in the interior will in consequence be greater.

The smaller the heat conductivity, the steeper the temperature gradient during cooling. Therefore, dangerous cooling

* Compare Howard.(23)

stresses may form in objects of smaller size than would otherwise be the case. This may be one reason why alloy steels appear to be more susceptible to the formation of flakes than carbon steel.

It may be questioned, however, whether flakes are as rare in carbon steel as is generally assumed. In order that a flake may be detected, the surrounding fracture should be fine-grained. Otherwise, the contrast may not be sufficiently marked to allow the flake to be distinguished from the fracture. Large-sized objects of carbon steel are generally not heat-treated or, if they are, the grain produced is never so fine as that of heat-treated alloy steels. Hence it is not unlikely that many cases of flakes in carbon steel have escaped notice. So-called shattered zones in rails and tires, in the author's opinion identical with flakes, are discussed below.

The rôle played by inclusions in causing flakes has been emphasised by many authorities. When conditions are such that a flake is about to start, it seems self-evident that discontinuities such as inclusions will present nuclei, from where flakes may begin, and on the whole will favour formation of flakes, the more so the greater the amount of inclusions. The opinions expressed that flakes are due to "dirty" steel, or poorly deoxidised steel, and statements to the effect that flakes have disappeared after the steel-melting practice had been improved, are probably correct, inasmuch as the inclusions constitute a secondary cause of the formation of flakes. The author believes, however, that flakes may be produced in steel of great purity, and thinks that the present investigation furnishes examples of this. On the other hand, flakes can probably be avoided even in steel rich in inclusions if the cooling conditions after hot-working are properly controlled.

The influence of variations in forging practice, such as amount of reduction and rapidity of blows on the formation of flakes, seems to be slight or *nil*. The influence of temperature in hot-working is probably greater, but is still certainly to be counted among the contributory causes of flakes. The position of the blank in the ingot appears to be of little account in this respect.

In view of the importance ascribed by Giolitti^(3, 4) and Sommer and Rapatz⁽¹⁴⁾ to areas of separated ferrite, assuming such areas to be the starting-points of flakes, it is interesting

to note that the flakes studied by the author occurred in hyper-eutectoid steel, in which cementite, but not ferrite, had separated, probably before the flakes formed.

The tentative explanation offered by Mathews⁽³⁾ that flakes may occur after completion of hot-working, constituting a series of internal bursts, further the method mentioned by Priestley,⁽¹⁰⁾ among other means suggested, of transferring the forging to the annealing furnace before it cools much below its critical point, are in perfect agreement with the author's conclusions.

SILVER STREAKS IN ALLOY STEELS.

So-called silver streaks as described by Rawdon⁽²⁾ differ from flakes in that they are elongated. The author suggests that silver streaks are flakes which have formed in a previous cooling operation, and have been elongated without welding together in subsequent rolling or forging. It may be assumed that in certain alloy steels, with high concentration of alloy metal, flakes, once formed, will be rather persistent as cracks, due to the difficulty with which such steel welds together, even if the surfaces are not oxidised. Silver streaks were not found in the present investigation.

SHATTERED ZONES AND TRANSVERSE FISSURES IN RAILS.

Transverse fissures in rails have been the subject of numerous papers and discussions in American technical literature. After concluding his present investigation of flakes, in searching for literature on the latter subject, the author's attention was directed towards the former on account of the great similarity between flakes and the defect that probably, or at least sometimes, provides the nucleus for transverse fissures in rails.* This similarity or identity has been previously pointed out by several authorities.†

Transverse fissures are cracks, sometimes found in the head of steel rails after they have been in service. It is generally agreed that they are fatigue cracks, starting from a nucleus somewhere in the central portion of the head and gradually spreading,

* If the author had studied the transverse fissure literature before taking up his investigation, it would probably have saved him much time and effort.

† For instance, Wickhorst,⁽¹⁸⁾ Rawdon.⁽²²⁾

finally reaching the surface, if the rail be not removed before this stage. On two points connected with this kind of failure opinions differ, viz.:

1. On the nature of the nucleus of the fatigue crack.
2. On the predominant cause of the repeated stresses that are responsible for the fatigue fracture.

Howard, who has presented several interesting contributions on this subject,^(14, 21, 23, 24, 25, 27) early took the stand that transverse fissures were mainly the result of too heavy wheel loads, the physical and chemical characteristics of the steel being contributory causes only. He demonstrates that the impinging pressures from the wheels have a cold-rolling action on the tread portion of the rail, thus setting up internal compression in this part balanced by internal tension in the interior of the head. The repeated tension stresses caused by the external load—these stresses being combined with the accumulated internal stresses mentioned—cause interior rupture that gradually spreads outwards. The internal stresses remaining in the rail head from the cooling after rolling⁽¹⁸⁾ add their effect to that produced by the cold-rolling action of the wheels. He states that the nuclei of transverse fissures commonly present a silky appearance.

P. H. Dudley^(18, 19) emphasises the fact that the nucleus of the transverse fissures, with rare exceptions, is not a point, as would be the case in a pure fatigue fracture, but an area of granular appearance, and often of considerable size—up to 0.625 inch. He considers this area to be an original crack produced in the cold-straightening or gagging operation in the mill. The cracking of the interior metal is explained by assuming weakness in this part, due to segregation, delayed transformation, chemical or mechanical defects. Cases are known when rails have been completely fractured in the straightening press, the fracture generally displaying a core of brittle metal. Dudley gives statistics covering about 900,000 tons of rails, in which 1113 cases of transverse fissures occurred. In this case the percentage of transverse fissures in rails rolled direct from ingots was found to be about ten times as high as that of such fissures in rails rolled from reheated blooms. This evidence points strongly to the conclusion that manufacturing processes, and the resulting condition

of the steel as it leaves the mill, have great influence on the subsequent behaviour of the rail in the track in regard to the development of transverse fissures.

Bronson ⁽¹⁸⁾ gives interior brittleness as the fundamental and prime cause of transverse fissures. The brittleness may be caused by improper composition of the steel—too high percentage of hardening elements, principally carbon—high rolling speeds and low finishing temperature, and rapid or improper cooling conditions for the rails on the hot-beds. With Dudley, the nucleus of the transverse fissure is considered to be an actual crack formed in straightening as a result of the brittleness postulated. Bronson also supports this statement by referring to rails broken in two in straightening, the fracture radiating from a non-ductile centre.

Wickhorst ⁽¹⁸⁾ agrees with Dudley and Bronson on the point that the nucleus of the fissure is an actual crack, and demonstrates a longitudinal section, deeply etched, of the head of a transversely fissured rail, in which section numerous cracks are seen.

Comstock ⁽¹⁷⁾ etched longitudinal sections of heads of transversely fissured rails with Stead's reagent, and arrived at the conclusion that the tendency for transverse fissures to form is greater in rails containing high-phosphorus streaks. The fact that rails rolled from reheated blooms were superior was attributed by him to better diffusion of phosphorus brought about by the reheating.

Waring and Hofamman ⁽²⁰⁾ were able to demonstrate on deeply etched longitudinal sections that original cracks existed in the heads of new rails as well as in a new rolled tire and a new rolled wheel. No inclusions were found between the faces of the cracks, nor any heterogeneity in the microstructure of the steel. The cracks were found to extend through the crystals as well as following the boundary lines.

On discussing ⁽²¹⁾ this new evidence several speakers questioned the conclusion that the cracks existed prior to the etching, suggesting that they were formed during etching as a result of internal strain in the metal. Howard, however, accepted Waring and Hofamman's conclusion in regard to the presence of cracks in new rails and tires, and believed the cracks to be shrinkage cracks formed during cooling after rolling. In support of this conclusion he reported that he had examined a rail that displayed

shattering cracks in the interior of the head, but had no cracks in a short distance from the hot-sawed end. On this occasion he presented the analysis of cooling stresses, which is quoted elsewhere in the present paper.

Rawdon ⁽²²⁾ demonstrated, by the use of iron dust suspended in kerosene and magnetising the specimen, that the defects found in rails that had developed transverse fissures exist prior to any etching. He found the cracks to be intracrystalline. The metal appeared to be sound. It could not be stated whether the cracks were formed in the mill or in the track.

Howard ⁽²³⁾ gives the following summary of information gathered on "shattered zones":

"Shattered zones are interior manifestations, being surrounded with walls of unshattered metal. The shattering cracks in rails are located along the middle of the head and at the junction of the web and base. The cracks themselves are of appreciable size in two directions, but in their third dimension are very minute. The minimum distance separating their walls is probably much less than 0.00002 inch. No foreign inclusion is contained in the cracks. They both follow grain boundaries and pass through the grains of the steel. They are not associated with other structural defects, nor peculiar to segregated areas, except in so far as they are prevalent in the harder grades of steel. The softer grades of steel, so far as present observations have covered the subject, are free from shattered metal. The shattering cracks appear to be of thermal origin—that is, they are cooling or shrinkage cracks. They are acquired presumably after the last pass in the rail mill. The hot-sawed ends of rails have been found unshattered. The cracks occupy zones in the section of the rails, which upon cooling acquire a state of initial tension, and have not been found in those parts which are left in the final state of compression. Experimental treatment has shown the susceptibility to display similar cracks in rails direct from the hot-saw, not displayed when reheated after cooling. In steel tires the disposition, size, and orientation of the cracks are even more suggestive of a thermal origin than those in rails."

Howard states further ⁽²⁷⁾ that "it has not been ascertained whether the presence of shattered metal in the head promotes the development of transverse fissures by furnishing a nucleus

from which they may extend, or, on the other hand, whether the internal strains caused by the wheel pressures are diffused and expended in the looseness of the central zone when shattered metal is present. Shattered rails are found which have not displayed transverse fissures, and transversely fissured rails are met with in which there is no evidence of a shattered zone."

Comstock⁽²⁴⁾ states that Howard's hesitancy in accepting the identity of the nuclei of transverse fissures with the transverse cracks of the shattered zones seems hardly justified. Rawdon⁽²⁴⁾ questions Howard's idea as to the possible retarding action of an internal zone of shattered metal upon the formation of transverse fissures, on the ground that several incipient transverse fissures formed in close proximity to each other have proved to develop further, consequently have shown no "diffusive action" on the internal stresses. Wickhorst⁽²⁴⁾ maintains that it had been noticed that the simple transverse fissure surface developed from a granular spot or nucleus. He accepts Howard's explanation that the original cracks are shrinkage cracks.

The present situation in regard to the occurrence of transverse fissures in rails in America is described by Bronson⁽²⁸⁾ as follows :

"The number of fissures has not materially decreased, though the rate per 100 miles of open-hearth steel in service is now about half of that seven or eight years ago. The product of certain mills is almost immune from this type of failure."

The author offers the following suggestions regarding shattered zones in rails and transverse fissures. Shattered zones in rails are probably cooling cracks, as suggested by Howard, and consequently identical with flakes. At first sight there seems, however, to be a difference in the law of their arrangement, flakes in rolled bars generally being longitudinal, whereas internal cracks in rails appear to be sometimes longitudinal, but more frequently transverse. If the author's view be correct, of cooling stresses being superimposed upon remaining deformation stresses, the resultant stresses determining the orientation of cracks formed, it may be assumed that the difference in manner of reduction in the last pass between the rolls—open and closed grooves respectively, different amount of spread—is the determining factor in this respect.

The conclusion by Dudley and Bronson that the cracks

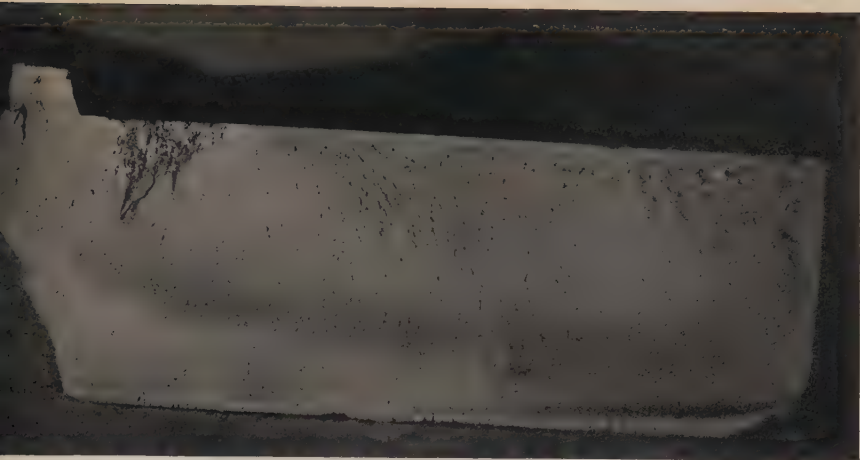


FIG. 6.—Fracture of hardened disc from 160 mm. forged bar. $\times 1.3$.

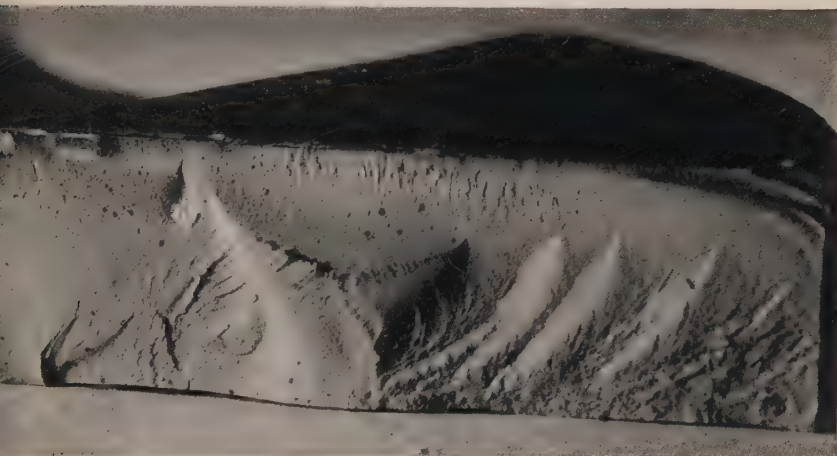


FIG. 7.—Same as Fig. 6.

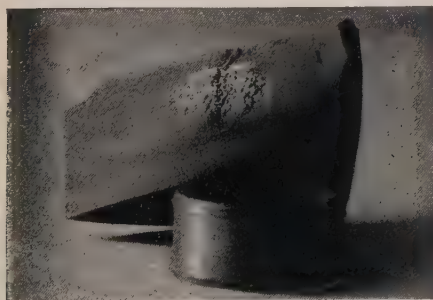


FIG. 8.—Fracture of disc from 2-inch bar, cut with the oxy-acetylene flame. $\times 1.2$.

NOTE.—Figs. 6 to 8 and 11 have been reproduced full size; Figs. 9, 10, 12 and 13 have been reduced to approximately two-thirds original size.

FIG. 9A.

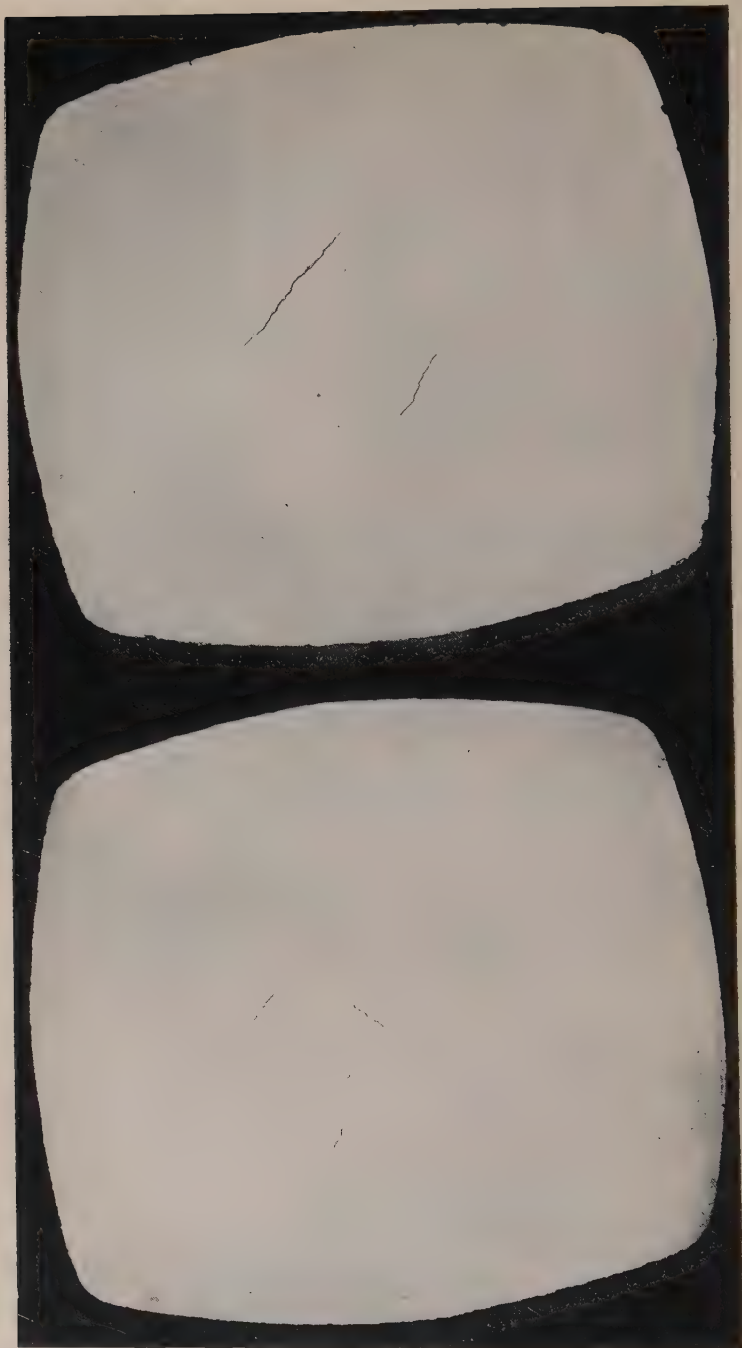


FIG. 9B.

Sections of 95X95 mm. billets. Polished with emery paper. Treated with iron dust on magnet. $\times 1.5$.



FIG. 10A.—Central section, parallel to the side, of ring 5A, test series 4. $\times 1$.

FIG. 10B.—Central section, parallel to the side, of ring 6A, test series 4. $\times 1$.

Polished with emery paper. Treated with iron dust on magnet.

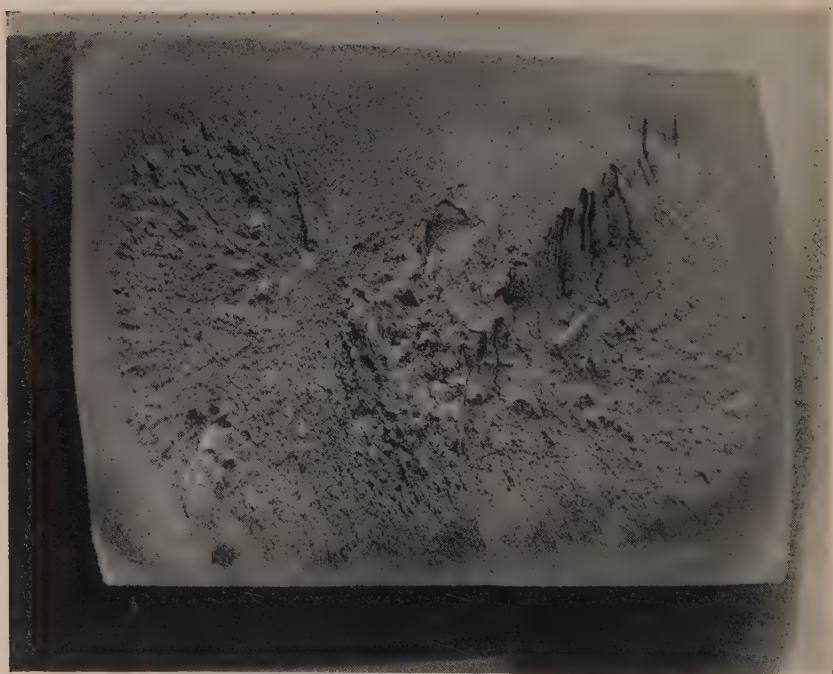
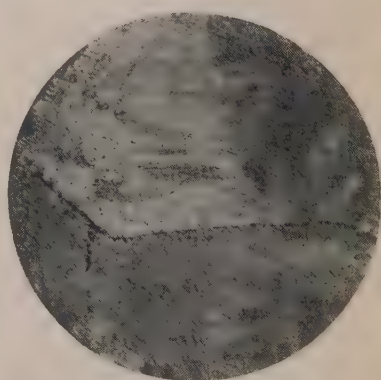
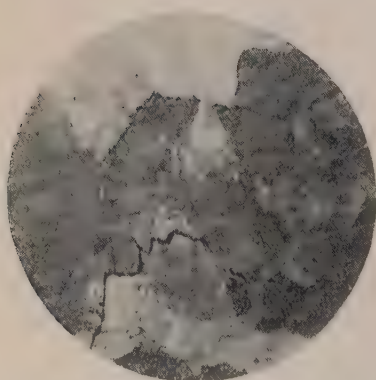


FIG. 11.—Fracture of ring F, test series 5. $\times 11$.



FIGS. 12 and 13.—Microstructure of rolled billet 110 \times 110 mm. with flakes.
Etching 1 per cent. HNO_3 in alcohol. $\times 1000$.

observed were formed in cold-straightening is not probably correct. The existence noted of a core in the fracture of rails completely broken in straightening points to the fact that this core existed as a crack prior to the straightening.

It has been convincingly demonstrated by Howard that the cold-rolling action of the wheels gives rise to accumulating internal compression at the tread, and to accumulating internal tension in the interior of the head up to a certain limit. When the repeated external stresses, created by the wheel loads, are superimposed upon the pre-existent internal stress distribution—either in the moments when a certain portion of the rail is bent upwards under the loads from two adjacent wheels, or when the wheel passes this portion, exerting a wedging action on the interior of the head (Howard)—favourable conditions for the starting of fatigue fracture are present in the region of the head, where internal tension had accumulated.

It seems self-evident that the presence of internal cracks in this region will greatly facilitate the beginning of fatigue fracture. As is well known, sharp cracks are very effective as notches in promoting fatigue failure. Instead of a hypothetical diffusive action from such cracks on the internal stresses, it would be expected that in the lack of sufficient support from the interior of the head, due to the shattered condition, the cold-rolling effect on the tread would proceed further and to greater depth than would otherwise be the case. The increased volume of cold-worked and expanded metal in this zone would induce increased tension in the interior. Fatigue fracture would thus be hastened.

The conflicting opinions as to whether the prevention of shattered zones would do away with the development of transverse fissures in rails are based upon different interpretations of fractures examined. Apart from the difficulty of proving the absence of an original crack in a fatigue fracture of this kind, it seems with the present knowledge at hand that the matter could be easily put to an actual test. After some preliminary experiments the proper cooling conditions for rails after rolling could be established, which would ensure freedom from internal cracks—as judged by the use of deep-etching or the magnetic iron-dust test—without causing softness or other undesirable reduction in strength. The behaviour of such rails in the track would then give the answer.

SUMMARY AND CONCLUSIONS.

Internal cracks, previously denominated snow-flakes, flakes, or hair-cracks, and found principally in certain alloy steels, have appeared in large-sized bars and forgings of high-carbon chromium steel for ball and roller bearings. The formation of flakes has been studied by rolling and forging experiments, carried out under varied conditions.

It has been found that such flakes when present invariably formed during cooling after the final hot-working operation, and that their formation is prevented by retarded cooling. The defect may therefore be designated as cooling cracks.

Suggestions are given as to the proper method of retarding the cooling to prevent the formation of flakes, at the same time avoiding the undesirable effects of slow cooling on the structure and on the physical properties of the steel.

The mechanism of the formation of flakes as a consequence of cooling stresses has been discussed, and the influence of large dimensions emphasised.

The significance of other factors, such as amount of inclusions and composition of the steel, as contributory causes of flakes, has been discussed.

It is believed that the reheating and the hot-working practice are of minor consequence in this respect.

So-called silver streaks in alloy steels are believed to be flakes that have been elongated in subsequent hot-working without welding together.

The so-called shattered zones in rails are believed to contain cooling cracks, formed in cooling after rolling, as suggested by Howard, and consequently identical with flakes.

The mechanism of the formation of transverse fissures in rails has been discussed.

The author wishes to acknowledge his gratitude to Mr. O. Hjorth, President of the Hofors Co., for kindly granting him permission to publish this investigation, and to Messrs. A. Strandell and O. Michaelsson for the unhesitating willingness they have shown in carrying out the rolling and forging experiments suggested by him.

Above all, he is indebted to Mr. Albert Olsson, chief metallurgist of the Hofors Steelworks, for his never-failing interest and helpful criticism during the course of the investigation. In fact, the author feels that he would not have succeeded in bringing this work to its conclusion but for Mr. Olsson's enthusiastic support.

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DISCUSSION.

Dr. W. H. HATFIELD (Sheffield) said Mr. Hultgren was undoubtedly dealing with a problem of the greatest importance to all alloy steel producers. The question of snow-flakes—which was an American term—had been and was a serious question on the other side of the Atlantic, and it was interesting now to know that it was also a trouble in Sweden. It had been to some extent in the past a trouble in Great Britain, but as far as the works with which he (Dr. Hatfield) was connected it might interest the members to know that the matter was completely under control, so much so that some years ago when an incident of the kind came up he discussed it with the director in charge of the particular works who, in a very broad-minded manner, said: “If, then, what we think is correct, we can make snow-flakes,” and the result was that that director did what from an industrial and manufacturing point of view was a very sound thing to do, actually reproduced intentionally the defects, and then said, “We will avoid the defects in the next cast,” the result being as he had predicted. That was an actual demonstration that in practice the difficulty could be overcome, and, as he had said, his firm had entirely overcome it and had now no trouble. Mr. Hultgren would probably like to know from whence the trouble came. He could assure him that his (Mr. Hultgren's) conclusions would not be helpful in preventing him from having snow-flakes in his steel, and he must realise that when the engineer or the manufacturer took over the billets and made crankshafts and articles of that kind which had to be quenched and therefore cooled with extreme rapidity, the steel, if potentially capable of developing the cracks and requiring to be nursed through the steelworks in the way indicated by Mr. Hultgren, obviously would develop those potential cracks during heat treatment so long as the cause was there. Reading the summarised deductions of previous investigators so ably put forward in the paper, it would be seen that almost every item of steel manufacture had been held responsible at some time or other for the production of snow-flakes. It was said, to begin with, that it was the refining operations in the furnace; in the second place, that it was the casting temperature; and, again, that it was the speed of casting, the size of ingot, uphill cast or downhill cast, quick heating in the rolling-mill, and excessive draught in rolling. All those items of process had been given as the cause, but in their own works it was found that the difficulty was entirely eliminated by controlling the reactions in the furnace, the casting temperature, and the speed of casting in relation to the size of the ingot; and that the trouble was purely an ingot one. Had he had time during the last few years to prepare a paper

dealing with the subject, it would have given him great pleasure to present it to the Institute ; it was only through the inability to find the time that that paper had not been brought forward, because he knew that the firms with which he was associated would have been only too delighted to publish the data. The present occasion gave him the opportunity of saying where the trouble was, and there was no doubt whatever that it was in the ingot. Mr. Hultgren stated that it had been found that such flakes, when present, invariably formed during cooling after the final hot-working operation, and that their formation was prevented by retarded cooling. How could it be affirmed that, inside the billet or bloom, cracks were not present previous to that operation ? It was impossible to do so unless the ingots were examined, which had not been done, and there was no evidence in the paper of careful consideration of the actual metallurgical side before the rolling-mill. Possibly he (Dr. Hatfield) could supplement a little the information which Mr. Hultgren had given with regard to the very interesting nature of the defects when they did occur. During the war, in America the trouble was a very serious one indeed, and in going into the matter, with a desire to help, most curious phenomena were discovered. A piece of steel could be sectioned and examined without finding any evidence of defects, but when the piece of steel was etched defects were developed. What were found were not necessarily defects but might develop into defects ; in other words, they were not necessarily separations of surface. Sometimes they were, but sometimes they were only planes of great internal stress, and an acid attack would develop that stress in such a way as to produce ruptured separation of surface. He had read the paper with the greatest interest, but could assure the author that his deductions were not correct, that there was a very definite explanation of the trouble, which was located in the ingot, and that in their own works they had had no difficulty in controlling the matter.

Mr. H. BREARLEY (Member of Council) said he suffered from the disability of not knowing what a snow-flake was. According to the conclusions reached by Mr. Hultgren it appeared to be a clink. It seemed to be clear to people accustomed to working alloy steels that defects called hair-cracks, which Mr. Hultgren associated with snow-flakes, occurred, and had occurred in thousands of different objects when those objects had been cooled off in a furnace. In the illustrations to the paper a picture was given of what was called a snow-flake, and if the remarks had been confined to appearances such as those reproduced in the picture it would have been possible to obtain an idea that would be continuously getting clearer ; but in some respects he (Mr. Brearley) had found it useful to read the paper backwards. First, Mr. Hultgren had summarised everything in the well-known phenomena called cooling clinks or cooling cracks, and said he thought those were entirely responsible for what he termed snow-flakes, and illustrated as snow-flakes in Figs. 6

and 7. He (Mr. Brearley) would not say that all the defects reproduced in Figs. 6 and 7 (Plate XIV.) were entirely due to the ingot-making process, but certainly a number of them were. A similar appearance to that reproduced in Figs. 6 and 7—and he was continually referring to the illustrations, because it was that type of defect that he was talking about—could be caused also during the forging operation. Mr. Hultgren was speaking mainly of steels containing about 1 per cent. of carbon and $1\frac{1}{2}$ per cent. of chromium, and he was industrially associated with the ball-race making trade. He (Mr. Brearley) had had some association with ball-race making for ten years before he saw anything that bore the slightest resemblance to a snow-flake. For some years afterwards he did not see another snow-flake until the war period, and during that time, as was well known, all kinds of shifts had to be adopted to get the material required, and one of the particular shifts he was associated with consisted in getting some iron-workers to forge ball-race steel. Iron-workers were not accustomed to the delicate heating of materials, and when they forged material like ball-race steel they were apt to produce what Mr. Hultgren called snow-flakes in very disagreeable quantities. He did not agree that what he called snow-flakes could not be removed by heat treatment; he thought they could be removed if the mechanical continuity had not been broken down. If a really bad example were obtained heat treatment at high temperatures might not remove all the snow-flakes, but would remove a great number; but where continuity had broken down it was not to be expected that the snow-flakes could be got rid of by heat-treatment operations. If a crack were formed in a piece of material during the cooling operation it would naturally be expected that the crystal size of that fractured surface would correspond with the normal crystal structure of the mass of the material. The pictures Mr. Hultgren gave in Figs. 6 and 7 (Plate XIV.), and particularly the descriptions he gave of snow-flakes as fractures having a large crystalline appearance, were not normal; that was to say, they were not the normal size of crystals in well-forged bar, and therefore, coming back again to the type of appearance illustrated in Figs. 6 and 7, it was unlikely that things of that kind could be produced by cooling clinks in bars which were otherwise sound and had been well forged.

Mr. E. H. SANITER (Member of Council) said he had been interested in reading the paper, and still more interested in listening to the discussion. There seemed to be very considerable differences of opinion. He agreed with Mr. Brearley in thinking that Mr. Hultgren had talked about too many things when he was really only dealing with one, the cooling cracks. The word "flake" in America had been used for at least half-a-dozen different sorts of things that occurred in steel. It would be noticed that the work in the paper referred only to one particular class of steel, although the paper dealt with many. With particularly hard steels what the author called cooling cracks were clinks,

and the author's cure was a cure. Mr. Brearley had criticised Figs. 6 and 7; Fig. 8 could be included. Mr. Brearley had pointed out that the granular structure was very much coarser in the clink than in the remainder of the bar. He took it from the appearance of the fractures that that was an absolute proof that it was a clink. The fractures excluding the clink appeared to be the fractures of hardening. Heating up after the hardening process produced a fine structure, but the clink was in the rolled bar, and therefore the coarse grain was in that portion, and that was a proof that the portion was in absolute separation before the hardening operation took place. He was very much inclined to think that Mr. Hultgren's pictures proved his case, that those particular granular fractures which he showed were cooling cracks and had nothing to do with the steel-making in any shape or form.

MR. BREARLEY said his point was that the coarseness of those granular fractures illustrated by Figs. 6 and 7 was a good deal greater than it ought to be in a forged bar.

MR. T. H. TURNER (Birmingham) said the paper was interesting and useful, but he was not quite clear that there were not two distinct phenomena involved. It seemed to him that the illustrations on Plate XIV. were not necessarily the same phenomena as those shown on Plates XV. and XVI. Appearances like those shown on Plates XV. and XVI. could be produced in any nickel-chromium steel by cooling quickly. Arc-welding of a nickel-chromium steel or the unexpected arcing that occurred in some mechanisms would produce almost identical cracks which would be shown up by the method—an extremely good one—of using iron dust. The suspension of the iron dust in petrol was not always necessary even if the crack were smaller than could be seen with an ordinary magnifying glass. Often by rubbing over with a brush or pen-knife some of the fine iron dust produced during polishing with the finest emery that type of crack would be shown up. On Plate XV. the cracks appeared as diagonals on the section, and he would like to know whether they were not also diagonal to the length of the bar. Were the cracks being looked at endways?

THE AUTHOR said they were parallel to the axis of the bar.

MR. TURNER thought that was interesting, because the phenomenon was similar to a clink in the causes that produced it, and yet a clink would be at right angles to that particular form of crack, or nearly at right angles. One question which arose from Mr. Hultgren's conclusions was that since all those steels were used in England in the hardened condition, how was the flake to be avoided by a slow, suitable rate of cooling and rehardening? He could confirm that the type of crack was a very frequent source of fatigue fracture.

With regard to what Dr. Hatfield had said, he was not in a position to say that the defects did not start in the steel before it was worked, but would suggest that that was not the only way in which defects of the type were produced; certainly in very good nickel-chromium steels cracks might be produced by very rapid cooling, such as occurred after arcing.

Dr. HATFIELD said that in works such as those he was connected with the whole of the alloy steel must be cooled rapidly from a high temperature, and therefore must be subjected to very great internal stress, and if there were any weakness inside the steel the cracks would obviously be developed. Therefore it was beside the mark to say that the steel should be cooled slowly in the way described in the paper. If a steel were not potentially sound in the ingot it was of no service to the more serious engineering industries.

Mr. H. H. ASHDOWN (Openshaw, Manchester) said he was sorry that up to a point he could not agree with Dr. Hatfield's remarks. To a very large extent he agreed with Mr. Hultgren, because as far back as 1919 he introduced the subject in a short paper presented to the Sheffield Society, and Mr. Hultgren had practically confirmed word for word in his conclusions what he (Mr. Ashdown) had said in that paper. Those clinks did unquestionably occur in the cooling-down period immediately following the forging operations and did not develop on subsequent heat treatment, and he believed that was due to the refining that took place in between. It was possible to take a forging showing clinks and refine and quench it many times without the clinks developing. He first came across the trouble in 1914, many thousands of miles away, and he was fortunate in being able to make some very careful investigations which helped him very considerably when he returned to England. He thought there was great risk of the trouble occurring, but when the cause and the stage at which it developed were known it could be entirely obviated. It did occur occasionally, but those occasions were very remote. He agreed that it was very largely due to the presence of non-metallic inclusions in the ingot. In very many of the sections he had had the opportunity of examining the trouble did not occur in the dendritic area but began at the cessation of the dendrites, and that would account for Mr. Hultgren failing to detect those defects in the outside rings. In a number of samples he (Mr. Ashdown) had examined he had found clinks right in the area of inclusion, and in some cases the inclusions lay right across the silvery spots. During the war the trouble was very prevalent. He brought home some sections of such defective steel, and one or two American experts said that they showed exactly what was called in America the old "snow-flake trouble," and it was quite evident that Mr. Hultgren was trying to illustrate those clinks or the snow-flake. The paper would be of very great service, and he

would suggest that, provided care was exercised in cooling down from the forging operations, whether hammered, pressed, or rolled, the trouble would to a large extent disappear. The paper dealt with comparatively small forgings. His (Mr. Ashdown's) firm were often handling forgings of from 10 to 50 tons weight with a length of from 10 to 80 feet. Such forgings could not be buried in charcoal dust and means had to be devised to prevent too rapid cooling from the forging conditions. When that was done such troubles practically disappeared.

Mr. T. SWINDEN (Sheffield) congratulated Mr. Hultgren on his very important work, which must have been of a very laborious character. He should like to refer in particular to the type of defect illustrated on Plate XV., Figs. 9A and 9B. He was not at all clear that those defects were similar to those illustrated in Plate XIV., to which reference had been already made. Unfortunately, he had had considerable experience of the defect which was illustrated in Fig. 9B, and the difference was that the fissures or cracks did not present a coarsely crystalline area such as was shown in Figs. 6 and 7, but were silver bright areas, except where they occasionally went out towards the surface when they were oxidised. The trouble was most pronounced, in the speaker's experience, in two types of steel, both made in the electric furnace—magnet steel of the ordinary 6 per cent. tungsten type, and a steel containing about 1 per cent. of carbon and 2 per cent. of manganese. In the early days the defect was very pronounced and could be definitely traced to non-metallic inclusions, or at any rate inclusions were associated with the worst of the defects, and it was reasonable to ascribe the defect to them. Aluminium was cut out entirely in the finishing processes and titanium was used instead and a considerable improvement resulted, but the defect was not entirely removed. From the type of the defect could be assumed the conclusion that Mr. Hultgren had now reached—namely, that the actual fissures did arise after rolling or forging owing to their shape and disposition, but it was most difficult to find any correlation in forging practice. Different forges were tried and different methods of heating and cooling, but none satisfactorily overcame the trouble. Although defects to which he referred were developed undoubtedly after forging, or during forging and cooling down, he felt quite certain that the reason for them was to be found in the steel-making process, from the fact that they were definitely overcome by modifying that process. The line of attack was to reduce the melting voltage and to pay particular attention to slag conditions and to reduce the casting speed. The work was done some three or four years ago, but he had made inquiries recently as to whether the defect had again developed, and the reply was that it was never now seen in the billets from 10-inch ingots or 8-inch ingots, but very occasionally it was seen in billets from 6-inch ingots, which again, he thought, proved definitely that casting speed expressed in seconds per foot rise up the mould was a very important factor. Whatever criticism might be levelled against the paper, he had

no doubt Mr. Hultgren felt very happy, because he had solved a definite difficulty which existed in his own works. He thought the conclusion was correct up to a point, but that the tendency for the defect to be developed in the cooling down after rolling or forging was really controlled by steel-making processes.

Mr. W. T. GRIFFITHS (Woolwich) said he did not know quite what previous speakers had in their minds when they said that they knew the cause of hair-cracks; but was not there a possibility that the remarks made on both sides could be correlated? It seemed fairly obvious that since it was possible to quench a steel without fracture after the retarded cooling treatment such as Mr. Hultgren suggested, the steel could stand very much greater stresses than those produced on air-cooling. Was it possible that a weakness might develop during the slower air-cooling? Was it something that might come out of solution in the steel in the case of the slowly cooled material which was kept in solution and did not exert its deleterious effect when the steel was quenched? He only put that forward as a suggestion, but he might say that in a short paper which he was presenting at this meeting he was drawing attention to the fact that there was at least one impurity in steel which went into solution at high temperatures and came out on slow cooling—he referred to nitrides. He did not say that they had anything to do with the particular trouble under discussion, but it might be that by not paying attention to proper melting and casting conditions there was a chance of including in the steel some other impurity which would come out of solution on the comparatively slow cooling in air. If that came out along the austenite grain boundaries a certain weakness might be produced here, giving rise, on fracture, to the large granular structure characteristic of the so-called snow-flakes.

Mr. HULTGREN, in reply, said the defect dealt with in the paper was, perhaps, more varied in its occurrence than he had previously thought, and he believed it was also more complicated in its manner of formation than some of the contributors to the discussion seemed to think. He had tried to solve a certain definite practical problem, and he had the assurance of the manufacturers that that problem was now done with. It might be that what were called snow-flakes in the literature, for instance, in regard to nickel-chromium steels in some cases was not identical with what he had described; at least it appeared so from the discussion.

He did not think his evidence had been questioned as far as that particular chromium-steel problem was concerned. Still it was said by Dr. Hatfield that his deductions were not correct. Dr. Hatfield gave no evidence for the opposite view, and his statement was therefore difficult to discuss.

He had shown in figures how snow-flakes in certain cases were

present, and in other cases not. The question of flakes being present and not being detected was disposed of by the repeated determinations by the magnetic method. It would have been interesting to have heard from Dr. Hatfield the methods used and the evidence obtained, in figures—the number of cases over an extended period—in order to prove his contentions.

He did not deny, as he had stated in the paper, that the quality of the steel must be of influence. What he claimed was, first, that the particular type of cracks described was formed in the process of cooling after hot-working, because in no case could he detect any after retarded cooling. Since the cracks were formed during that cooling process, they must, moreover, be a result of cooling stresses. If that were admitted, he thought the main factor in the formation of such flakes must be the cooling stresses, and not the condition of the ingot. It would be dangerous and useless to lay more stress on the ingot condition in that connection than he had done. If such cracks had formed in the ingot, they would naturally not have the appearance they actually possessed after deformation; they would be elongated. Also, judging from the rolling experiments, when flakes were welded together after comparatively slight reduction, it was improbable that cracks present in the ingot would not be welded together during the successive stages of hot-working. Consequently, if the discussion were confined to the particular defect studied by him in chromium steel, he did not think he had reason to withdraw any of his statements.

It had been mentioned by Dr. Hatfield and others that in hardening similar defects might be expected to be formed, but that was not altogether clear. In the first place, the initial temperature of cooling differed in those two cases. Furthermore, during cooling in air, for suitable dimensions of the object, there must be a peculiar distribution of stresses that would not prevail during cooling in water or in oil. The time and temperature at which the interior portions would be subjected to the dangerous stresses would be different, and it was not obvious for that reason that the same phenomenon would occur. Further, as pointed out by Mr. Ashdown, such steel was not hardened after hot-working, but after the structure had been refined and strengthened by annealing. The fractures illustrated were always obtained after annealing and hardening.

He had the greatest respect for Mr. Brearley's opinion, but he was not in accord with some of the opinions which he had expressed. The flakes described were not areas of weakness; they were actual cracks, as seen under the microscope at high magnification. Otherwise they could not be seen without any exaggerating effect, such as by the method suggested. He believed Mr. Brearley was misled by the appearance of the flake surface. Mr. Brearley had said that the flake surface was too coarse, and did not represent the fracture of a well-forged object. That could be easily explained. After passing the Ar1 transformation, the previous austenite grains would be divided into

a number of grains or colonies of sorbite and lamellar pearlite, as seen in Fig. A. In breaking a forged bar, he thought it would be agreed that usually the fracture did not follow the previous austenite boundaries. Whatever course it might take in relation to the sorbite grains, the degree of coarseness of the fracture would probably reflect the grain-size of the sorbite and pearlite grains. In the case of flakes, as he had shown, the crack as a rule followed the previous austenite boundaries. No doubt that would explain the difference in coarseness. Since the temperature of formation was different in those cases, it was no wonder that that difference in appearance would result. The term "clinks" that had been suggested probably was preferable, but he was not



FIG. A.

sufficiently conversant with the English language to be able always to choose exactly the right word.

He was glad to find Mr. Ashdown could confirm his own conclusions. The inclusions were given by Mr. Ashdown as the cause of the flake formation. On that point he thought caution was needed. When looking for a local cause, it might seem plausible to ascribe the defect to a number of inclusions present, but his point was that microscopical examinations of cases with and without flakes should be compared. The numerous examinations he had made did not bear out the assumption that inclusions were responsible for the cracking.

The subject was a very complicated one. Perhaps there was an optimum of size as well as of rate of cooling that would produce cracking. Also the influence of composition should be further studied. He hoped in the future to be able to throw more light on the problem, but certainly it was too wide a subject for one man, and he hoped others who were interested would try to check his conclusions, or to contradict them—by evidence.

CORRESPONDENCE.

Colonel BELAIEW (London) wrote to express his great interest in Mr. Hultgren's paper, and in the questions raised. Having lost actual touch with the foundry and rolling-mills practice for over ten years, he would not have ventured to offer any remarks were it not for the fact that, even as far back as about fifteen years ago, the problem of hair-cracks and silver streaks had been brought to his notice by some of his friends from the Ural works.

In the first instance, it might be observed that defects designated by the Russian equivalents of hair-cracks ("Volosovini"), snow-flakes ("Svetlovini"), and silver-streaks were considered as different defects due to different causes. So, for instance, hair-cracks were considered, more or less unanimously, as having their origin in blowholes, and their remedy was sought accordingly in supervising and controlling the foundry practice. On the other hand, in the opinion of the distinguished metallurgist, General E. Hermonius, flakes (and silver-streaks) were linked up with internal cracks, formed during cooling, thus corroborating Mr. Hultgren's views. General Hermonius suggested that during the period of incomplete solidification the mother-liquid was being forced into those cracks, thus giving rise to the streaks of silvery or shiny appearance.

Mr. FRANCIS B. FOLEY (Chattanooga, Tenn., U.S.A.) wrote that flakes, or snow-flakes, as they were called, developed during the war in the States chiefly in nickel ordnance steels manufactured in plants unaccustomed to the fabrication of alloy steels. They were notably absent from material supplied by plants in which such steels of large section had been manufactured as a routine product for years.

At least two, but probably many more, defects in nickel ordnance steels were classed as flakes. In fact, it came about that practically any visible defect in the fracture of a tensile specimen was so designated. In a particular instance the fracture of a bar that gave the following results—

Tensile strength . . .	47,000 lbs. per sq. in.
Elastic limit . . .	47,000 " " "
Elongation per cent. . .	0.0
Reduction of area . . .	0.0

showed a defect which was obviously a crack. In the case of what might be termed true flake, the average tensile test of 152 bars which displayed that phenomenon was :

Tensile strength . . .	97,000 lbs. per sq. in.
Elastic limit . . .	68,120 " " "
Elongation per cent. . .	11.59 in 2 inches.
Reduction of area . . .	20.48 per cent.

The average tensile test of 182 bars of like material similarly treated, but showing no defect, was :

Tensile strength . . .	101,580 lbs. per sq. in.
Elastic limit . . .	68 268 " " "
Elongation per cent. . .	19.51 in inches.
Reduction of area . . .	37.53 per cent.

The true flake, therefore, did not seem to be a crack, but rather an area of low ductility. Mr. Hultgren's work appeared merely to show that steel of carbon 0.7 per cent., chromium 1 per cent., and manganese 1 per cent. would crack under certain conditions of cooling. Nothing seemed to have been determined concerning the nature of real flakes. The ordnance steel in which those flakes were found was of hypoeutectoid composition. Frequently, in the "as forged" condition, he (Mr. Foley) had observed under the microscope actual cracks which, for the most part, followed the ferrite network (Fig. 3), but occasionally took a short cut through the pearlite, giving every reason to believe that they were caused by a parting between the crystals while the steel was in the austenite region of temperature. It was fair to assume, therefore, that those cracks were produced by thermal contraction in the steel during cooling. Regulating the cooling rate, as Mr. Hultgren had determined, would no doubt eliminate such cracks.

The other type, or what could be termed a true flake (which there was no evidence to show was a crack), had some other cause not to be found in regulating the cooling rate. Workers would certainly be delighted in America, were they able generally, to hold forging temperatures below the 1150°C . which Mr. Hultgren had used as a high-temperature limit in his work. In works where four out of every five forgings produced flaky test-bars, temperatures of 1370°C . and higher were measured on the ingots during heating for forging. Following a period during which an attempt was made to hold forge furnace temperatures to a maximum of 1204°C ., a record of twelve acceptances out of fifteen submissions of forgings were made.

Cracks developed by the use of gasolene and steel dust no doubt were prevented by controlling the cooling rate, but it did not appear that such cracks had been identified as flakes. The defect shown in Fig. 7 appeared, as nearly as could be judged from the picture, to be a flake, while that in Fig. 6 did not look like a flake, but appeared to be an intercrystalline crack, and Fig. 8 might be either (Plate XIV.).

Mr. T. M. SERVICE (Glasgow) wrote that Mr. Hultgren stated in his paper that he had formed the opinion that the flakes or hair-line cracks were not present in the ingot as sent to the forge or rolling-mill, but no evidence was given in support of that view. Would he in his reply state whether the ingots, when cast, were allowed to go cold in either of two ways :

- (1) Cooled in the mould to atmospheric temperature.
- (2) After setting, removed from the mould and allowed to cool in air to atmospheric temperature.

If neither of those two methods were employed, how long elapsed between finished casting and charging to heat for forging and rolling, and approximately about what temperatures were the ingots when charged into the heating furnace?

Might he suggest that Mr. Hultgren, if he had not already done so, might take discs from ingots treated as in (1) and (2) and see if he found cracks in ingots by (2) method similar to what he found in bars allowed to cool in air?

Having experienced trouble with hair-line cracks in nickel-chromium steel, and having analysed the methods adopted for the manufacture of finished forgings, he (Mr. Service) had come to the same conclusion as Mr. Hultgren, namely, that in steel made under satisfactory conditions hair-line cracks were produced by stresses set up by unequal cooling. It was a well-known fact that in certain classes of work where some forgings were made solid and others were forged hollow, hair-line cracks were only discovered in the solid pieces, although the solid and hollow forgings might be made from the same cast of steel.

He had had sections from ingots of nickel-chromium steel which were cast and allowed to go cold at atmospheric temperature and not annealed, polished, and etched with dilute HNO_3 , and those discs all showed hair-line cracks. After forging and annealing, repolishing and etching, some discs showed no hair-line cracks, others showed only a few, but in every case the number was infinitesimal in comparison with what they were before the forging.

The hair-line cracks of which he had experience did not show any connection with non-metallic inclusions. In the ingot section they all appeared as radial cracks of varying length but no appreciable depth.

A nickel-chromium forging made recently had the top end portion cut off and allowed to cool in air, then when cold it was cut partly down on the centre line; but as it was too hard it was annealed at 620°C. , and when cold parting was completed. One portion was surfaced, polished, and examined for hair-line cracks, and a great many were found. The forging made from the same ingot and annealed immediately after the forging operation did not show any trace of hair-line cracks.

The theory advanced by Mr. Hultgren, that hair-line cracks were due to stresses set up by differential cooling from a high temperature, covered the facts which had come within his (Mr. Service's) experience in recent years.

MR. HULTGREN, in a further reply, wrote referring to Dr. Hatfield's opinion that snow-flakes were not necessarily separations of surface, and that rupture might be developed by etching. Those remarks were of course not intended to apply to his (Mr. Hultgren's) work, in which etching was not used as a means of detecting snow-flakes. At the beginning of his research, before the details of the magnetic detecting method were worked out, it sometimes happened that only a few cracks



FIG. 14.—Section of 160 mm. round bar, No. 3, Table iv., air-cooled end (the same bar as fig. 6). Polished with emery paper. Treated with iron dust on magnet. $\times 1$.

were seen on a section that on renewed treatment showed many more, the latter usually smaller. The failure to employ a sufficiently sensitive detecting method, before etching was tried, probably lay at the root of the opinion expressed by Dr. Hatfield and others, that snow-flakes were sometimes not actual cracks. On the other hand, cracking at the surface of stressed steel objects due to the attack of an acid was well known. Dr. Hatfield spoke of steel being potentially sound or unsound. He (Mr. Hultgren) was convinced, from his practical experience in heat-treating ball and roller bearings, that the steel under discussion was not only potentially but actually sound. It had established its value to the industry, which was quite "serious" in every respect, not the least in regard to drastic heat treatment. Dr. Hatfield's remarks on that point were properly answered by Mr. Ashdown. As to the metallurgical side before the rolling-mill, the author wished to refer Dr. Hatfield to p. 120, conclusion 1, and to p. 122. In planning the investigation it was decided, for reasons stated in the paper, to direct attention mainly to the final operations. The course adopted was justified by the results obtained; the difficulties were overcome. Therefore a detailed study of the ingot condition, however desirable, was not essential in arriving at the cause of the defect. Dr. Hatfield opposed his main conclusion that the cracks were formed during cooling after hot-working, but did not offer any alternative theory whereby the consistent absence of cracks after slow cooling could be explained. The views to which Dr. Hatfield apparently had committed himself years ago, and which he now strongly advocated, probably contained a great deal of truth, but in his (Mr. Hultgren's) opinion they missed the main point, namely, the influence of the cooling rate after hot-working. Dr. Hatfield's desire to strengthen his position by categorical statements had carried him too far when he said that the conclusions in the paper "would not be helpful in preventing him from having snow-flakes in his steel." The practical results obtained and set forth on p. 136 (compare footnote) were completely disregarded by Dr. Hatfield.

It might be of interest to other steel-makers to know the opinion of the manufacturers concerned on that point. That was expressed in the following statement, put forward by kind permission of the management of the Hofors Steelworks :

"Mr. Axel Hultgren, of Aktiebolaget Svenska Kullagerfabriken, in Gothenburg, has asked us for a statement regarding the method suggested by him to prevent flakes in chromium steel of large dimensions by retarded cooling. Complying with his request, we wish to state that from the middle of November 1924 to the middle of June 1925 we have rolled 1694 tons chromium steel of dimensions 75 to 150 millimetres round; that all those bars have been examined for flakes at both ends; that all bars were found to be perfectly free from the defect.

"Before we adopted the retarded cooling in the middle of November 1925—i.

M

1924 flakes occurred in a good proportion in bars over 75 millimetres round. The flakes were, however, in most cases situated so near to the centre that the steel was perfectly satisfactory for its purpose (ball-bearing rings). It was not necessary, therefore, to reject the bars.

"Since by the adoption of retarded cooling flakes immediately and completely disappeared from our products without any other change having been made in the manufacture, the relation between the occurrence of flakes and the rate of cooling stands before us as an indisputable fact.

"HOFORS BRUK.
OLOF HJORTH.

HOFORS, *the 27th June 1925.*

A.B. SVENSKA KULLAGERFABRIKEN."

In further reply to Mr. Brearley, he had confined his paper to cracks in rolled and forged steel objects. Mr. Brearley's statement that hair-cracks occurred in thousands of different objects of alloy steel which had been cooled off in a furnace was not quite clear to him. The question was: Had non-elongated hair-cracks been found in objects that had received substantial reduction in hot-working with no cooling off intervening, and had then been left to cool sufficiently slowly in a furnace or otherwise? Since Mr. Brearley confined his remarks to Figs. 6 and 7 (Plate XIV.), apparently questioning the identity of that type of defect with those shown in section on Plates XV. and XVI., the author regretted to state that several of the illustrations submitted with his original paper had to be omitted owing to lack of space. He considered it necessary to introduce some of those figures, which he thought would dispel Mr. Brearley's doubt on that point. Plate XVII.A showed the cross-section of the round 160-millimetre forged bar No. 3 of Table IV. (air-cooled end), the axial fracture of which was partly shown in Fig. 6. Fig. 15 (Plate XVII.B) showed the fracture of the disc in Fig. 9A through the crack to the left, the fracture as usual being obtained after hardening the disc. In Fig. 16 (Plate XVII.B) was shown part of the fracture of the disc illustrated in Fig. 9B, that fracture running through the two cracks to the left. In both those fractures the cracks that were previously revealed by the magnetic test had opened towards the surface of the disc and had been oxidised in heating for hardening. Fig. 16 revealed another crack that had no access to the surface and consequently had retained its lustre. Having demonstrated that the cracks were formed during cooling, he did not believe any longer, as he had done at the outset of his investigation, that they could be formed during the forging operation, as Mr. Brearley had indicated. He would like to mention here that in chromium steel of the composition given a certain definite kind of porousness might be seen after rolling or forging at too high a temperature. Perhaps Mr. Brearley would recognise what he was referring to if he said that that porousness appeared as very small, usually disconnected bright spots in the fracture as obtained after hardening,

those often being arranged in streaks in the centre. Under the microscope those separations were seen to have what was sometimes called a "negative" shape, similar to shrinkage cavities in an ingot. They were not identical with such cavities, however, not being sufficiently drawn out in the rolled bar. Such pores were easily distinguished from flakes, but it should be borne in mind that they, like other defects, might form nuclei for the formation of clinks or snow-flakes during cooling. On the question whether snow-flakes could be removed by heat-treating alone he did not like to be dogmatic, but he had seen no proof of it, and still doubted it, because the snow-flakes found by him were actual separations of surface. It might be possible, however, that their size could be somewhat diminished by heating. In regard to the coarseness of the flake surface as compared with that of the fracture of a well-forged bar, he hoped his verbal reply had satisfied Mr. Brearley. He would, however, add that what he characterised by the term "coarse" was the appearance of the flake as compared with the fracture of refined and hardened steel, where the defect was usually detected. He did not state that the flake was necessarily and always much coarser than the fracture obtained before refining. That was illustrated to some extent by Fig. 11, where the flakes were not conspicuous on account of the fracture in the central part being coarser than that of the peripheral zone, an effect of limited depth of hardening. Magnified illustrations of a snow-flake were given in Figs. 17 and 18 (Plate XVII.c). The effect described in the paper and illustrated by the diagram in Fig. 1 was here seen.

He greatly valued Mr. Saniter's contribution, particularly his opinion that his illustrations proved his case, and that the defects described had nothing to do with the steel-making in any shape or form, although the latter statement was certainly more categorically expressed than any conclusion drawn by him. Might he suggest that what Mr. Saniter called his (Mr. Hultgren's) "cure" was rather a method of prevention? He was aware of the fact that the word "snow-flake," and particularly the word "flake," had been used in America for various defects seen in the fracture which were not identical with those he had described. Before having established the nature of the defect he was studying, he could not find a better name for it. As to the application of his conclusions to other classes of steel, he would refer Mr. Saniter to No. 5 of his concluding remarks.

Mr. Turner, like Mr. Brearley, thought that the illustrations showed more than one type of defect. It was interesting to note that Mr. Turner had come across similar defects produced in very good nickel-chromium steel by quick cooling after local heating, such as in arc-ing. That case was somewhat similar to the effect of cutting with the oxy-acetylene flame described on p. 133. He did not quite understand Mr. Turner's remarks regarding the orientation of clinks. Mr. Turner first suggested that clinks would be diagonal to the length of the bar; later he said that they would be at right angles

to the cracks shown in the paper, consequently transverse, since those cracks, although varying in direction in the section, were always roughly parallel to the axis of the bar. Those two statements did not appear to agree. Was not Mr. Turner thinking of clinks formed beneath edges and corners of cylindrical or square objects? Such clinks, according to his (Mr. Hultgren's) experience, might be diagonal to the axis.

It had been a great pleasure to him to listen to Mr. Ashdown's account of his experience that apparently referred to other steels than chromium steel, and consequently justified the author's attempt to include such steels in his conclusions. Mr. Ashdown had later been kind enough to supply him with a copy of his lecture, in which the subject of flakes was mentioned.¹ In that lecture Mr. Ashdown stated that the flakes were "minute clinks that had taken place due to tension in the forging during cooling, or on subsequent heat-treating." He was glad to know that Mr. Ashdown later had changed his views on the latter point, and that he was now, in regard to the nature and manner of formation of flakes, completely in agreement with the author's conclusions. The only difference of opinion existing between Mr. Ashdown and himself concerned the effect of inclusions, to which, according to Mr. Ashdown, the flakes were largely due. That might be true in some cases, but the author still thought that it did not apply to the steel he had studied. Mr. Ashdown had further made the interesting observation that flakes often occurred at the cessation of the dendrites, and in this connection referred to the fact mentioned in the paper, that when rings were trepanned from solid bar, flakes were never found in the outside rings. The author agreed that the segregation inside the shell of columnar dendrites might assist in assigning to the flakes a locality where they would preferentially form. He wished to state, however, that in the case referred to, flakes could not be expected to occur in the outer rings for reasons of distribution of cooling stresses, the outer ring being fairly thin as compared with the diameter of the bar.

Dr. Swinden had very clearly stated his position and drawn the line between his agreement and his non-agreement with the author. It was interesting to know that not only did Dr. Swinden acknowledge the practical solution of the particular problem, but also that he had reached the conclusion that the fissures in tungsten and manganese steel studied were formed during cooling after rolling or forging. The fact that the trouble was overcome by modifications in the steel-making process, details of which were given, was of great interest, and he (Mr. Hultgren) accepted that view. However, if, as stated, the fissures formed during the final cooling, he could not possibly imagine that they would not have been prevented by *sufficiently* slow cooling. He ventured to say so, because Dr. Swinden had not definitely stated that such cooling was tried. He noted that fissures were now occasionally

¹ "The Value of Observation in Works Practice," *Proceedings of the Sheffield Society of Engineering and Metallurgy*, 1918, No. II.

seen in billets from 6-inch ingots, but not from larger ingots, but was unable to accept that fact as a definite proof of the influence of casting speed only. Surely other factors, such as amount of reduction in rolling, also varied with the size of ingot, and might play their part. He referred to his reply to Mr. Brearley regarding the illustrations of flakes in Tables I., II., and III.

In reply to Mr. Griffiths he would not recommend quenching chromium steel after forging followed by slow cooling without an intervening annealing to refine the structure. Apart from that, the roughness of the forged surface would be liable to cause quenching cracks. After annealing and machining, however, rings, balls, and rollers of that steel could be, and were usually, water-quenched without danger of cracking. As to the suggestion made of a constituent separating out on air-cooling but not on quenching, he had no opinion to offer. In that connection it might be pointed out that the possible influence of the cementite network in hyper-eutectoid steels like that should not be lost sight of in a future study of composition in its relation to formation of flakes.

It was of interest to learn from Colonel Belaiew that snow-flakes were encountered in the Ural Works about fifteen years ago. It appeared, however, from the statement of General Hermonius as quoted that the explanation given referred to cracks formed in the ingot. That explanation was not therefore in agreement with his (Mr. Hultgren's), as suggested by Colonel Belaiew.

He was glad to have Mr. Foley's opinion, since he was one of those American writers who were the first to publish investigations on the flake problem. Mr. Foley accepted the conclusions regarding regulation of cooling as applicable to the prevention of cracks in nickel ordnance steels, but maintained his opinion, already referred to in the present paper, that there was another type of defect, apparently of similar appearance in the fracture, which he called true flakes, and which he did not consider to be cracks. Mr. Foley based that opinion on the average results of numerous tensile tests which gave (for bars with flakes as compared with those without the defect) appreciably lower values for elongation and reduction of area, some loss in tensile strength, but no loss in elastic limit. He (Mr. Hultgren) did not think that the presence in the bar of an internal crack of moderate size, at right angles to the length of the bar, would influence the elastic limit noticeably, since the possible effect would be local in relation to the gauge length of the extensometer. He admitted, however, that the reduction of tensile strength was unexpectedly small, assuming that actual cracks were present. It would have been of value if Mr. Foley had tried the magnetic method to decide that point, as Rawdon had done in simultaneous work on steel of approximately the same composition. He would remind Mr. Foley that Rawdon came to the conclusion, without reservation, that flakes were actual discontinuities; also that other American writers spoke of flakes as being cracks.

Furthermore, the fact that Mr. Foley and his co-workers made their observations on pulled test-bars served, he thought, to confuse the issue somewhat. He referred to the well-known fact that a tensile fracture might be partly crystalline and partly fibrous, due to the difference in the mechanism of rupture caused by heterogeneity in the steel of another order than that under discussion. Contrasts of that nature would not be found in fractures of hardened pieces, the fracture being obtained by shock. He was inclined to think that the term "snow-flake" or "true flake" should preferably be assigned to the actual cracks, on the existence of which they both agreed, and wondered whether that was not more in conformity with the American usage of the term. Speaking about forging temperatures, Mr. Foley seemed to overlook the fact that most of the steel experimented with by the author contained 1 per cent. carbon. He could assure Mr. Foley that all flakes illustrated in the present paper were actual cracks.

In reply to Mr. Service, the ingots were removed from the moulds when cooled to approximately 700° C. at the surface, and then left to cool in the air. He had not stated in the paper that hair-line cracks were not present in the ingot. What he had said was that if such cracks existed, they would not persist during rolling or forging, and then appear as snow-flakes—that was, non-elongated cracks in the finished object. Mr. Service suggested that he should take ingot sections with the object of studying their soundness. He had actually done so at the same time as he was pursuing his forging and rolling experiments, but discontinued the former work after the solution of the trouble had been found as a result of the latter. The information he had gathered on ingots was therefore incomplete. Such work as he had done, however, appeared to agree with Mr. Service's observations. He referred further to his reply to Dr. Hatfield on this point. He thanked Mr. Service for the information he had given, and was glad that he endorsed the statement that hair-line cracks were due to stresses set up by differential cooling.

Before concluding he wished to define his views on certain aspects of the question more clearly than he had done in the paper, on the following points :

1. The defects defined as flakes or snow-flakes in the present paper had the appearance of coarse, bright, non-elongated spots in the fracture of objects that had been rolled or forged ; the term did not refer to defects found in ingots.

2. Snow-flakes were cooling cracks or clinks, caused by hydrostatic tension in the interior during a period in the cooling process, when differential contraction occurred between centre and periphery as a result of faster cooling of the former during that period, possibly assisted by expansion in the latter due to the Ar1 transformation.¹

¹ From cooling curves recently taken at different points within the mass of cooling objects the author had concluded that that might be a possible factor of influence. That had also been suggested to him independently by Mr. B. D. Enlund.

3. Cooling cracks formed in ingots after solidification might also be caused by the agents mentioned in paragraph 2. Such cracks might properly be called hair-cracks, but still were not identical with snow-flakes in worked objects.

4. Reminders of cracks or cavities in the ingot, of whatever origin, might persist unwelded to a greater or less extent during rolling or forging, but could not appear as non-elongated defects in the finished object. They might even form the nuclei of snow-flakes, but in no case were they to be regarded as identical with the latter.

5. In view of the striking similarity between the defect studied in the paper and that found in nickel and nickel-chromium steels, as described and well illustrated in the literature, particularly by Rawdon,⁽²⁾ and, further, considering statements made by several contributors in the present discussion, he (Mr. Hultgren) ventured to adhere to his belief that those defects were identical in nature and manner of formation with those described by him. The complications arising out of permanent deformation before fracture in studying the fractured surface were not considered in this connection.

It was most desirable that comparative experiments using varying rates of cooling after hot-working be made on steels of various compositions by those who were in a position to do so. He would suggest that in carrying out such experiments a careful search for clinks should be made by means of the magnetic detecting method or any method equivalent to it in sensitiveness. The influence of other factors could then be profitably studied with the view to ascertain the actual stage and temperature at which the cracks form, and thus arrive at a complete theoretical explanation of the phenomenon.

Iron and Steel Institute.

THE DETECTION OF STRAIN IN MILD STEELS.

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INTRODUCTION.

MANY of the best-known metallurgists and engineers have applied themselves to the subject of strain in metals, directly or indirectly. Nevertheless, it is still impossible or extremely difficult to detect, by ordinary means, strain in a mild steel, unless the material has been drastically cold-worked and is severely strained. Slight permanent strain present in steels deformed but little cannot be recognised under the microscope by the ordinary worker. Few would be able to differentiate microscopically, or indeed by any other means, between two pieces of the same mild steel, the one stressed below and the other just above the elastic limit. Were such differentiation possible, information could be obtained of undoubted value to designers and users who are interested in the behaviour of new constructions, or in the cause of the failure of some steel part.

While employed in an engineering works, one of the present authors carried out the usual type of post-mortem investigations necessitated by the failure in service of various types of mechanisms. It was then thought that the location of strained areas in steels would be similar to the stress concentrations indicated by Coker ⁽¹⁾ and his collaborators in their work with polarised light, and transparent bodies stressed within their elastic limits. It was felt, however, that it was not safe to go far in applying those results to the common metals and alloys, materials whose structures differed fundamentally from those of such transparent bodies.

The strain markings shown by Fry,⁽²⁾ and Strauss and Fry, were therefore noted with great interest, and attempts were made to apply the specialised method of tempering and subsequent etching developed by these workers to some typical fractures, but without any real success.

These experiences led to the idea that it might be possible to develop a method of investigation which would enable the metallurgist to detect the presence of strain, the stress direction which produced it, and possibly even its magnitude. This would lead to a better understanding of present shapes of test-pieces, and possibly to the introduction of designs of test-pieces, which would give fundamental values for the material irrespective of their size, and hence to a reduction in the present excessive waste of good metal and labour in the standardised preparation of test-pieces. Ideally, the strain detection process should be as simple as the development of the structure by etching or the taking of a sulphur print. It would then enable the engineer to see how his mechanism had been stressed in actuality, for stress and resultant strain must always be related. Possibly it would enable him to test periodically certain highly important components for signs of yielding at dangerous corners or in thin sections.

Such a method of strain detection is unfortunately still an ideal, but it is thought that the following account of work done in this direction may help to make it the basis of useful practice of the future.

METHODS OF STRAIN INVESTIGATION EXAMINED BY THE AUTHORS.

Reviewing the experimental work carried out by the present authors in the light of such published work as they have been able to consult, they note that the methods of the engineer, chemist, physicist, and metallurgist have all been applied to this problem.

It has been found that strain sometimes produces visible surface markings, and also influences the mechanical, chemical, physical, and metallurgical or metallographic properties of the metal. Research work upon absolutely divergent lines has contributed to provide methods which are capable of showing, in

certain circumstances, whether a metal is severely strained or relatively strain free.⁽¹³⁾

This work can be summarised under the following headings, which may be regarded as rallying-points for the general attack upon the question of practical strain detection :

1. *Direct observation*—" *Lüders' Lines*."
2. *Direct measurement*.
3. *Hardness and density variations*.
4. *Analysis of gases evolved on solution*.
5. *Solution potentials*.
6. *Corrosion effects*.
7. *Electrical resistance variations*.
8. *Magnetic effects*.
9. *X-rays and miscellaneous methods*.
10. *Microscopical or metallographic methods*.
11. *Recrystallisation*.
12. *Special methods of etching*.

Each of these methods will now be considered in some detail. The first three methods suggest the viewpoint of the user of metals, the engineer.

1. *Direct Observation*—" *Lüders' Lines*."

On testing, in tension or otherwise, bars which are either very carefully polished or covered with a uniform coating of rust or mill scale, it is observed that as soon as the yield point is reached lines appear upon the polished surface, or the scale begins to flake off. The metal deforms markedly in certain places, and as the scale is comparatively inextensible it chips off above such places, which thus show up as light reflecting metal against the dark background of oxide. All surface films do not flake off equally readily, but with certain types of mill scale very distinctive lines are obtained which should apparently be taken as indicating that the metal has undergone mass deformation along a number of roughly parallel but independent wedges, between which the metal appears unstrained.

The phenomenon has been studied by many engineers who have observed these "Lüders' or Hartmann lines" in the course of tensile testing. Among others, Lüders,⁽³⁾ Hartmann, Cooper, Breuil, Gulliver, and Mason have written very interesting accounts of their observations in this respect, and have given excellent photographic illustrations of the effects produced. The contractile cross observed in straining a flat bar of almost any metal to its breaking point must not be confused with Lüders' lines, which are not observed in non-ferrous metals, so far as the authors' own experience extends. It is probable, however, that analogous phenomena will be demonstrated in such other metals, and that they will prove to lie along other angles than that typical of Lüders' lines.

The present authors have confirmed the occurrence of Lüders' lines in ordinary hot-rolled mild steels, and, as will be shown later, they have been able to bring out these strain lines with greater detail by special methods of etching.

These lines, bands, or, as they undoubtedly are, wedges of distorted metal, occur in all carbon steels, wrought iron, and pure iron, but only in the mild steels are they easily obtainable. Up till comparatively recently proof has been lacking of the fact that these markings on the surface of a strained specimen really indicate wedges of grain disturbance extending, when fully developed, right across the specimen. The photographs shown by the present authors illustrate sections cut through the specimens, and similar results can be produced in the same steel on other sections wherever desired. The continuity of the etch lines down the sides of rectangular specimens, enabling the same wedge of distortion to be seen on all four sides of the specimen, has permitted conclusive proof of the fact that Lüders' lines do indeed indicate wedges of distortion. The suggestions, which were made in connection with the results of the four workers named above, to the effect that the lines were due to folds in the surface or to the nature of the scale, and not to distortion of the metal below, are thus disproved. Similarly, it is erroneous to regard these lines as indications of mass slip along a plane. Slip planes exist in individual grains, but the mass distortion is by means of wedges having thickness, and not along one plane of mass slip, as has been suggested.

2. *Direct Measurement.*

Heyn⁽⁴⁾ showed very clearly in 1914 that if a bar be left with internal strains, produced by cold-drawing or other cold-working, the dimensions of the interior or exterior will alter if one or the other be machined away by drilling or turning. The outer portion is compressed elastically in certain cases, and therefore elongates when the core is drilled out and the internal strain thus reduced. The present authors have not repeated such experiments, as they do not give promise of a method of general applicability for the purpose they have in mind. They have, however, been able to indicate the location of permanently strained areas in certain specimens in a very simple manner, which appears to be worthy of mention.

In certain of their early experiments notched flat bar tensile specimens were used to provide severely and slightly strained areas. On filing the surface of one of these specimens, it was noticed that the file did not bite on the central area where the specimen had been reduced in cross-sectional area when elongated under the straining action of the tensile testing machine. This observation might well have been predicted, but as it was new to the authors they made and examined a series of variously notched flat bar tensile specimens. These were of mild steel, machined flat, and before being permanently strained in tension their surfaces were roughened by dipping in acid in order to increase the contrast produced by the subsequent machining. Instead of filing these specimens, as in the first case, they were all milled with a parallel-sided milling cutter. In this manner a clear definition of the areas reduced in cross-section was obtained by means of what was termed the "dirt" effect—that is, the badly strained parts remained dirty and the unstrained areas showed a brightly reflecting machined surface. Hence by photographing the specimens, after successive light cuts had been removed parallel to the surface of the bar, less and less of the dirty etched areas were retained, until these became merely small circles, showing the concentration of the strain at the point of the notch or at similar points of maximum strain. Figs. 1, 2, and 3 (Plate XVIII.) illustrate stages in so treating one of this series of flat bar tensile test-pieces. The bars were actually 9 inches long, but as

only the central part is of interest, only that part is here illustrated. Superimposing and somewhat idealising these three photographs, the strain concentration diagram shown in Fig. 4 (Plate XVIII.) is obtained, which is somewhat reminiscent of the beautiful coloured illustrations produced by Professor Coker. Fig. 4 is really only illustrative of the intensities of reduction in cross-section in a steel bar pulled beyond its yield point. Coker dealt with other and non-metallic materials stressed within their elastic limits. Figs. 1 and 4 show indications of Lüders' lines, a definite phenomenon occurring in mild steels, whereas the photo-elastic method would, of course, never indicate this. The production of Lüders' lines in this manner proves that the specimen is reduced in cross-section at every such line ; in itself an interesting point. The whole series of specimens tested in this manner by the authors cannot be reproduced here on account of the limitation of the space available, but Figs. 5, 6, 7, and 8 (Plate XIX.) illustrate the type of result obtained on different shapes of specimen treated in the manner described for Fig. 4. The method may be recommended to students and engineers as surprisingly instructive concerning the influence of holes, notches, and sharp corners.

3. Hardness and Density Variations.

Hardness is increased by cold-work, and it has been shown by McCance,⁽⁶⁾ and also by Moore and Greaves, that by means of systematic hardness determinations over a flat surface it is possible gradually to map out the location of the severely strained areas. The scleroscope and the small ball Brinell have both been used successfully for this purpose. The present authors have repeated such experiments, and have found the method good, but not accurate as to details, unless great care is observed both in obtaining an excellent surface polish and in conducting the actual hardness measurements. There is no apparent reason why scratch hardness determinations should not be equally successful, and yet polishing with emery, which may be regarded as a multiplication of scratch tests, frequently appears to give no indication at all of the strain details which it might be expected to find polished into relief. Perhaps, however, others have been more successful in this respect, for it has been noted that

indications of the lines observed upon the surface of oxidised specimens could also be seen on carefully filing or polishing the metal below.

The degree of hardening by plastic deformation of metals generally increases with increasing amounts of permanent strain. If a metal object originally of uniform hardness be unequally strained, the distribution and local intensities of the strain will usually be indicated by the differences in hardness from point to point.

Tensile test-pieces have been sectioned along their axes after fracture, polished on this surface, and tested at short intervals all over the section. Curves of equal hardness have thus been obtained which have been assumed to indicate strain concentrations. This method of strain-exploration has been extensively developed in certain research departments. It is, however, difficult of application to the irregularly shaped articles of general engineering practice, and is of necessity somewhat tedious and cumbersome. Nevertheless, strain-hardening is a definite phenomena in steel, as may be demonstrated in the following simple manner.

A bar of steel was stamped in several places with a punch, and the punch marks filed out. Strained in the tensile machine, the polished surface was everywhere destroyed except under the former punch marks, which became evident as raised polished areas. Repeating the experiment with a shorter bar tested in compression, the punch marks again became visible, this time as polished depressions.

Similarly, this strain-hardening below punch marks has been used to show up identification marks which had been filed off the end of a test specimen. On etching the flat surface the strained portions, below where the stamp marks had been, became visible, reproducing the original indentation markings.

The density of strained steel has been very carefully studied by O'Neill,⁽⁶⁾ but unfortunately the differences noted were so slight as to make the use of density measurements impracticable as a method of strain detection in metal articles of everyday use, even if the difficulty of applying density measurements to the mapping out of small strain differences be ignored for the moment.

4. *Analysis of Gases evolved on Solution.*

Turning now to the methods of chemistry, it is interesting to note that permanent strain in metal influences the chemical properties of metals. In a most interesting piece of work reported by Whiteley and Hallimond,⁽⁷⁾ it was found that the gases evolved from strained and unstrained metal varied in accordance with the amount of strain. It is difficult to see how this fact, even if confirmed, could have aided the present authors, so long as it was necessary to cut out small samples of the metal for testing in such a manner. Although strain may be indicated by this method, the location and distribution of the strain in a piece taken from service would be next to impossible, in the view of the present authors, since a specimen slightly strained all over might easily give the same result as one severely strained locally. They have therefore made no experiments in this direction.

5. *Solution Potentials.*

It is probable that the corrosion of steel in an acid is either dependent upon minute electric currents, or at least aided by them. In general, it is found that severely strained metal is corroded more readily than that which is unstrained. For example, if, after fracturing, a mild steel tensile test-piece be placed in hydrochloric acid, it will be noted that the $\frac{1}{2}$ inch or so of the steel nearest to the fracture, namely, the necked portion, will be corroded away much more rapidly than the remainder of the specimen.

Such observations suggested that the measurement of solution potentials over the surface of a partly strained specimen might be a means of mapping out the location and intensities of the strain in the steel. Attempting to do this with a needle-point as the searching electrode showed that the current varied with the distance of the needle-point from the surface tested. A searching electrode was therefore made by fusing a platinum point into a small inverted glass cup, so that when the rim of the cup was pressed upon the specimen the platinum point was held approximately 2 millimetres above the surface of the steel. When searching electrode and specimen were simultaneously connected

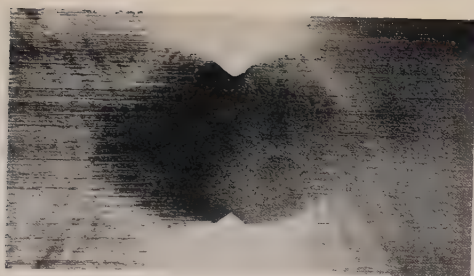


FIG. 1.



FIG. 2.

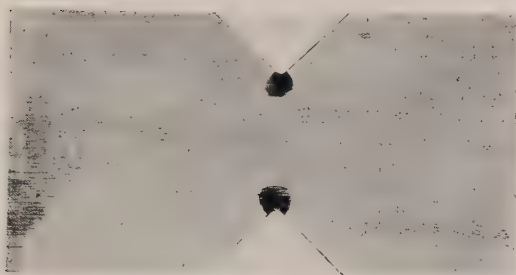


FIG. 3.

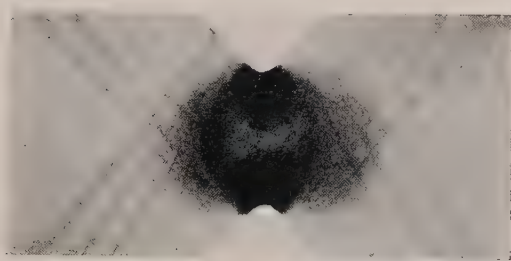


FIG. 4.

Flat notched bar strained in tension to 5 per cent. elongation on 4 inches.

Figs. 1, 2 and 3 show successive cuts removed from the surface by milling.

Fig. 4 illustrates the surface deformation map obtained by superimposing and slightly idealising the preceding photographs.

NOTE.—Figs. 1 to 14 have been reduced to two-thirds original size.

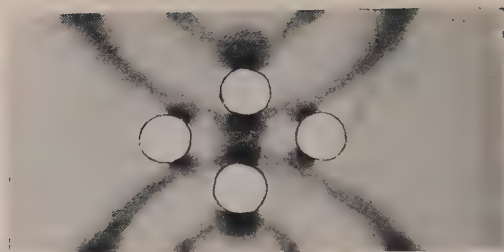


FIG. 5.

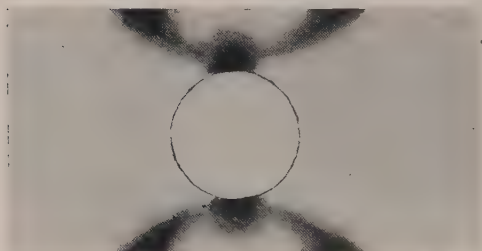


FIG. 6.

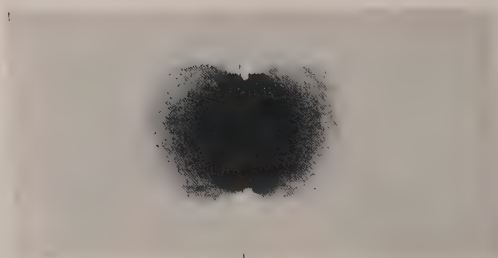
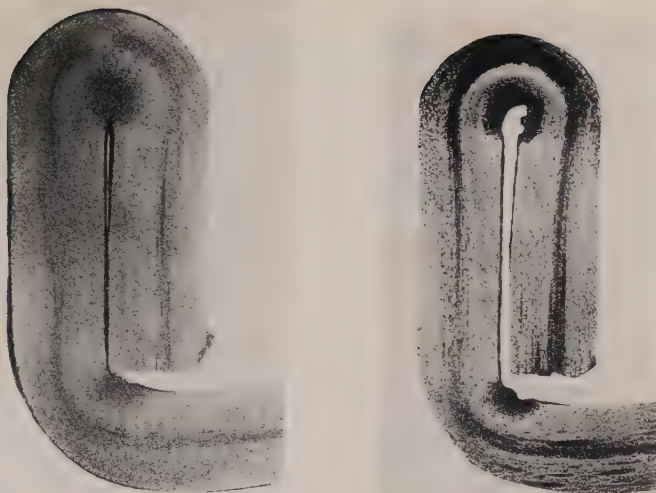


FIG. 7.



FIG. 8.

Slightly idealised surface deformation maps obtained from flat bars of the shapes shown, strained in tension to an elongation of 5 per cent. on 4 inches.



FIGS 9 and 10 show a bent specimen sectioned and etched for 10 minutes and 2 hours respectively in boiling 5 per cent. HCl. $\times 2$.



FIG. 11.—Right end of bar has been heated to redness before sectioning and etching. Strain markings developed under third indentation from left (water-cooled) end.



FIG. 14.—Flat notched bar, strained to 5 per cent. elongation on 4 inches, sectioned and etched. Oblique lighting reveals depth of etching.

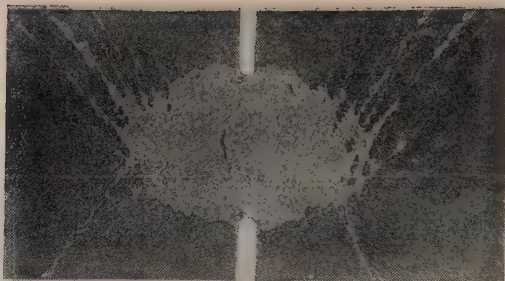


FIG. 12.—Markings in mill scale, or Lüder's lines, produced on flat notched bar strained in tension to 5 per cent. elongation on 2 inches.

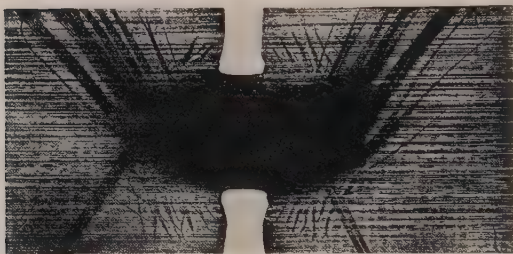


FIG. 13 —The same specimen sectioned and etched with Fry's solution, showing that Lüder's lines are the surface evidence of distortion wedges in the metal beneath.

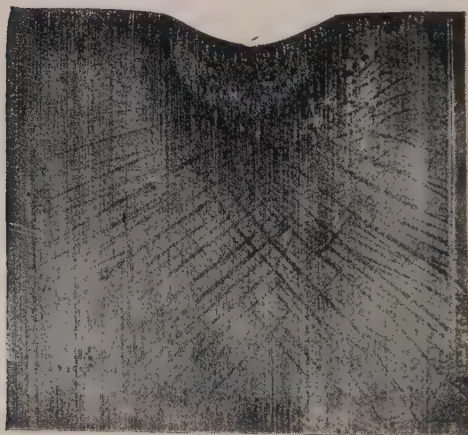


FIG. 15.—Etched section of mild steel strained by indentation and heated to produce abnormal grain growth.

NOTE.—Deformation wedges extend further than the area of abnormal recrystallisation. (Actual size.)

by wire to a millivoltmeter about 20 millivolts were registered. Unfortunately, this varied as the searching electrode was moved away from the wire soldered to the specimen, and thus masked differences which have been produced owing to local strains. To overcome this the searching electrode was attached by string so as to move in an arc about the point of connection with the other wire. No change in E.M.F. was observed as the electrode was moved from strained to unstrained material, and any difference must have been less than 0.1 millivolt. Possibly these experiments should be repeated without using the soldered joint for the other wire, but polarisation effects have also to be considered. As soon as the millivoltmeter needle ceased swinging it began to creep back again, owing to polarisation. By using the potentiometer and only allowing current to flow when the key was pressed, polarisation difficulties were lessened, but even so, no definite results were obtained, readings under 0.1 millivolt being erratic. Despite the lack of success with this method, it still appears worthy of consideration, and should be capable of producing interesting results if experiments were conducted using many different electrolytes.

It has been shown by Wood⁽⁸⁾ that if specimens of strained iron are immersed in hot liquid agar, or any colloid in neutral solution, to which has been added a few drops of phenolphthalein and potassium ferricyanide as an indicator for alkalinity, red and blue spots will soon form on the surface of the metal. The red colour denotes alkalinity, or uncorroded iron, while the blue indicates corroded iron. Considerable time has been spent by the present authors in an attempt to adapt this indication process to the practical determination of strained areas in steel specimens, but so far their efforts have been entirely unsuccessful. The difficulty appears to be in obtaining perfect neutrality in the colloidal solution, and, what is still more difficult, on the surface of the specimen.

The experimental difficulties here encountered were unexpected, and the authors still feel that some method could be devised employing a chemical indicator in gelatinous solution which would differentiate between strained and unstrained metal and form a record of strain location analogous to a sulphur print.

6. *Corrosion Effects.*

Some of the earliest experiments made by the authors during the present work related to the effects of the common acids upon strained steels. Bent specimens of Armco iron and mild steel were sectioned, polished, and etched with various concentrations of hydrochloric, nitric, and sulphuric acid, and it was found that although a more or less selective action occurred with all these acids, 10 per cent. nitric acid and 50 per cent. hot hydrochloric acid gave the best results. In the early stages of etching this selective action resulted in a darkening of the strained areas on the inside and outside of the bend, as shown in Fig. 9 (Plate XX.), which illustrates a bent specimen of mild steel rod etched for ten minutes in boiling 50 per cent. hydrochloric acid. Fig. 10 (Plate XX.) shows the same specimen etched for two hours and rubbed lightly on emery-paper. It will be seen that marked selective action has occurred. The centre line is due to segregation. With specimens made from Armco iron slight darkening occurs in the early stages, but no deep selective etching takes place. A number of broken tensile test-bars of different steels were sectioned and etched in a similar manner, but beyond the fact that the metal near the fracture became very deeply corroded, no selective action was apparent.

The effect of adding a colloid to the etching solution was tried. Using a small addition of starch solution a slightly increased contrast, due to the apparent whitening of the lighter areas, was produced on the bent specimens referred to above, but this disappeared as soon as deep etching began. Adding methylated spirit to the etching solution reduced the vigour of the attack, but did not increase the selectivity of action.

An unsuccessful attempt was made to measure the difference in solubility of deformed and normal steel in different strengths of nitric acid. Small pieces of strained and unstrained steel of the same size were suspended by strings in beakers of acid, and the decrease in size of the specimens was measured at intervals with a micrometer. The only fact that could be deduced from the somewhat erratic results obtained was that if the pieces were in separate beakers the strained sample dissolved more rapidly than the unstrained, while if the pieces were in one beaker the reverse occurred.

Strained specimens have been immersed in mercuric nitrate, mercuric chloride, stannous chloride, and other corrosive solutions to see if any phenomena analogous to the season-cracking of brass could be observed, but nothing of such a nature has been noted by the authors.

So far the results obtained appear to show that although etching specimens with the common acids does sometimes give a very general indication of distorted areas, no real strain figures of practical utility, such as are produced by the process later described, can be obtained by means of mere rapid corrosion by acids.

7. *Electrical Resistance Variations.*

The influence of stresses and strains upon the electrical resistance of a metal has been studied, and might possibly be used practically to detect strains. However, in experiments which the authors carried out, using two contact points, which were connected with a source of current and with apparatus for detecting slight differences in current flow, and could be moved so as to complete the circuit by loading the specimen under test wherever desired, it was found that contact variations and change in thickness of the specimen masked any variations of value in strain location. With specimens of constant shape and equally strained there is undoubtedly an increase in the electrical resistance of the steel almost directly proportional to increase of stress and strain up to the breaking point.⁽⁹⁾ It is nevertheless clear that the measurement of stresses or strains in structures or irregular sections by noting variations in electrical resistance is impracticable, as the cross-section of such members is often too large and irregular to permit of the detection of small differences. For these reasons the authors did not further investigate this method, as it could not measure or detect localised strains unless developed in some unforeseen manner.

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8. *Magnetic Effects.*

It is just possible that local strains might be detected in a mass of steel, owing to differences which strain produces in the magnetic properties of the metal. The detection of a minute crack by means of iron dust brushed over the surface of a

magnetised article requires for its success as fine a polish of the surface as possible. Any surface patterns which magnetic differences due to strain could produce would apparently require an equally good surface. Added to this drawback is the fact that, contrary to the proportionality of electrical resistance and strain, magnetic values first increase and later decrease, so that for heavy loads in tension the final value is actually lower than the original value. In compression also no straight-line proportionality with strain was experienced in the various stressed iron and steel specimens, whose magnetic properties were studied by Smith and Sherman.⁽¹⁰⁾

9. *X-Rays and Miscellaneous Methods.*

X-ray investigation is doubtless a most instructive and valuable method of examining strained metal, in that it may reveal such distortion of the space lattice as may prove to be the basic characteristic of strain in metals. Reference to the abstract sections of recent Journals shows that very much valuable research work has been done in this connection by workers in various countries, but the present authors have devoted no time to this study as a method of strain detection, for, although they are fully alive to its very great importance, it is not at present capable of adaptation to commercial investigations, and demands costly apparatus, skilled operators, and thin specimens for the production of good results.

The possibility of showing up strained areas in a thin specimen by allowing emanations from a radio-active surface to penetrate it and then fall on a photographic plate has, however, been investigated, although it was feared at the outset that the differences in density upon which the method depended for its success would be too small for the purpose required.

Radio-photographs of thin aluminium tensile bars were taken with both thorium and radium emanations. The latter yielded very fair photographs, and showed up a slight contractile depression in the test-piece distinctly, but no indication of other strained areas on strain markings was given. Possibly very thin sections of steel would yield results in this manner, but it is feared that this simple method is of but little present practical value,

The authors have experimented to some extent with a further group of miscellaneous methods, such as plating with copper, amalgamation with mercury, and etching with dry hydrochloric acid gas, but no promise of successful strain detection was obtained in such directions. The following and concluding group of experiments of a metallurgical nature have proved decidedly more instructive.

10. *Microscopical or Metallographic Methods.*

Numerous workers have, by means of a microscope, observed the slip-bands which are produced in individual grains, the elongation of equiaxed grains, the breaking into smaller grains of one big crystal, and the grain boundary ruptures, all of which may and do sometimes occur in the straining of metals.

Attempts have been made to correlate the magnitude of the deformation of a metal mass with the microscopical changes in structure visible on polished and etched sections.

Very severe strain is easily recognised in this manner, and the grain distortion or elongation encountered immediately below a machined surface is familiar. By examining a tensile test-piece, however, it is soon discovered that minute permanent strains are not readily detected.

Transverse and longitudinal sections of a mild steel tensile piece have been examined microscopically, and in one case reported by Sir R. Hadfield⁽¹¹⁾ a steel of much the same analysis as that examined by the authors gave the following results. With 10 per cent. reduction in sectional area the ferrite was visibly elongated, more markedly so at 25 per cent., and these features were exaggerated, the crystals being distorted along visible gliding planes at 40 per cent., and at 70 per cent. the individual grains were no longer definable, complete breakdown having taken place.

Certain etching reagents darken strained areas in mild steels to a greater extent than they do the relatively unstrained areas. It is, however, extremely difficult to detect the small differences in the amount of strain within, say, 5 per cent. elongation, by means of ordinary microscopical examination. The special methods of etching to be described later do permit of this, and

enable strain to be detected and located as soon as the yield point is reached, and before, say, 1 per cent. of elongation has been produced, whereas ordinary microscopical observation would not differentiate between test-pieces strained just below and just above the yield point.

Microscopical examination of the material in the distortion wedges appears to show at least three types of disturbance. The crystal grains exhibit slip, break up into smaller grains, or part from one another at the grain boundaries. The first is the more common, and probably the more important or fundamental phenomenon. Slip may be observed in every or almost every grain in the distortion wedges, but crystals exhibiting slip may also be seen in some places in the apparently undistorted material between the distortion wedges.

11. *Recrystallisation.*

The peculiar growth of certain grains at the expense of others, which occurs when strained mild steels are annealed within suitable limits of temperature, has been studied in recent years by many workers.⁽¹²⁾ The conditions governing such abnormal grain growth are somewhat better understood now as a result of their labours, but the use of this phenomenon to detect the location and magnitude of strains is at present outside the field of practical utility.

The excellent photographs given by Chappell⁽¹²⁾ of abnormal grain growth do not illustrate, as was suggested, the lines of flow in the deformation of the iron, nor do they fix all Lüders' lines in terms of crystalline structure, as may be seen in Fig. 15 (Plate XXI.), which shows deformation wedges reaching far below a recrystallised area of abnormal grain growth. Were it possible to correlate grain-size with strain, it would be possible simply to anneal the specimen suitably, polish, etch, and obtain a record of the strain. To some extent this is possible, but abnormal grain growth only tells part of the story of the permanent strain existent in the metal before heating it to produce the grain growth.

Another drawback to this method of strain detection is that abnormal grain growth is limited to low-carbon steels strained

and heat-treated within specified limits, and is, moreover, influenced by decarburisation such as may occur locally during the annealing.

12. *Special Methods of Etching.*

The successful use of special methods of etching for the detection of strain in steel is apparently quite a recent development. Strauss, in 1905, noted lines on a piece of cold-worked boiler plate etched in copper ammonium chloride solution. Fisher, in 1913, found similar lines near the sheared edges of sheet iron strips used as anodes in the manufacture of electrolytic iron.

All such marks were more or less valueless until Fry, in 1921, discovered a method of etching which showed such lines on sections, and upon which the present authors have spent much time. He was followed enthusiastically in Germany by a number of investigators.⁽²⁾ However, most though not all of them appear to have regarded Fry lines as newly discovered phenomena connected with temper-brittleness, and not to have realised that such lines indicate a fundamental characteristic of the straining of mild steels, and indeed of many if not of all carbon steels. It is true that up till now the authors have not been able to produce such lines on all carbon steels, but they have definitely identified Fry lines with Lüders' or Hartmann's lines. Most of the German work appears to have been upon pieces strained in compression or bending. The present authors have found similar markings in tension, bending, compression, and shock-strained mild steels.

Figs. 12 and 13 (Plate XXI.) show the same elongated notched tensile test-piece. Fig. 12 is a photograph illustrating lines in the surface scale, just as shown on similar test-pieces by Gulliver, and Fig. 13 is a photographic reproduction of the etch lines produced on a section cut parallel to the surface shown in Fig. 12.

The depth to which such lines are etched out is clearly seen in Fig. 14 (Plate XX.), which was photographed with very oblique lighting.

For the production of such lines Fry used a strongly acid solution of copper chloride, and rubbed the specimen from time to time with a wad. In principle this method has proved most successful in the authors' own work. Their experience in this

direction is described more fully in Mr. Jevons' paper, which is concerned more particularly with this part of the subject.

Briefly, it may be said, however, that distortion wedges are not indicated macroscopically by etching alone. A low temperature annealing in the range 200° to 600° C. or thereabouts appears to be necessary in all cases, since strained mild steel does not show distortion etch marks unless so annealed before etching. This fact is illustrated by Fig. 11 (Plate XX.), which shows a piece of mild steel strained in six places by similar indentations and then heated to a red heat at one end, and maintained so heated for twenty minutes while the other end was kept cool in water. Temper colours commenced at the third indentation from the hot end. After milling off the surface, the bar was etched. It will be seen that etching out of the badly strained areas and of the distortion wedges has only occurred in one particular part of the bar, thus indicating that the temperature to which this steel should be heated before etching for strain markings is below that at which temper colours are produced.

Heating within a wider range than here indicated may cause the markings to be etched out, but within a comparatively narrow range of temperature only are the clearest results obtained. Sometimes heating to 600° C. appears to make them vanish, but in other cases heating for several hours at 700° C. does not remove the tendency to etch out along distortion lines.

It is possible to obtain these etch markings upon articles which have not been especially heated in the laboratory, but which have been suitably heated during manufacture or service life.

Thus the punching of a rivet hole leaves local strain in the material, which latter is sometimes low annealed by the hot rivet, thus giving the combination necessary for the direct etching out of these deformation line markings. Hot galvanising or heating preparatory to tarring of cold-worked articles, finishing rolling at too low a temperature, or service in heated mechanisms, all give similar results.

OBSERVATIONS UPON THE STRAIN DISTORTION OF STEEL.

Observations they have made enable the present authors to state that in straining a four-sided specimen of mild steel in

tension distortion wedges begin to advance across the section as soon as the yield point is reached.

At first these narrow wedges of distorted material only advance along two planes at right angles to one another. At a later stage, when further straining occurs, the distortion wedges also appear upon two other planes roughly at right angles to one another and at 45° to the first two planes. All four planes, along which the distortion wedges advance, are roughly at 45° to the longitudinal axis of the specimen. Conformity to any constant angle is prohibited by the constant redistribution of stress which any local distortion of the metal structure entails. The distortion wedges are straight sided or curved sided. In cases where the stress has been applied from a curved object, as, for example, in the Brinell test or in drifting out a circular hole, the distortion wedges starting from the source of strain have curved bases and curved sides.

The specimen is reduced in cross-section wherever distortion wedges appear after elongation. The microstructure of the metal in such wedges exhibits slip, crystal breakdown, or grain boundary failure when seen under the microscope, after suitable treatment.

Lüders' or Hartmann's lines are the surface signs of distortion wedges. Wedge is here used advisedly, for the distortion is neither a surface phenomenon nor mass slip along a plane right through the section.

The first distortion wedge to appear always starts from the most highly strained locality, and advances across the section at the same time as it broadens at the base. Rupture only takes place after the distortion wedges have intersected one another all over the area of the failure.

Abnormal grain growth does not occur where two distortion wedges intersect, but does occur in the area where more than two such wedges intersect.

In the distortion wedges of a flat bar tensile specimen the metal appears to have started a movement towards the central axes. This result, which somewhat resembles the reduction in section of a piece of rubber when it is stretched, is probably due to crystal slip, which takes place in three directions towards two axes of the specimen—that is, one slip direction towards the apex

and two other directions parallel to the faces of the wedges, and opposed to one another. For other shapes of specimen distortion, wedges form in keeping with the geometrical arrangement of the stresses.

It is not clearly understood why distorted metal and undistorted metal so often lie side by side, in what almost amount to laminations, or why a second distortion wedge nearly always commences to grow before the first has grown to its full extent.

Small ball hardness tests upon carefully polished specimens have shown conclusively that the distortion wedges are definitely harder than the apparently unstrained metal lying between them. In ordinary commercial hot-rolled bars distortion wedges are produced in greater number, or appear more plainly, when the strain has been produced in the direction of rolling.

The etch patterns produced by the same type of strain applied transversely and longitudinally undoubtedly differ in their characteristic forms.

Specimens strained after they have been quenched from above 900° C. do not appear to show signs of the distortion wedges, which are obtained upon the same material strained in the as rolled or fully annealed condition.

CONCLUSIONS.

The authors have surveyed all the methods which appeared to give any promise of yielding a practical method of detecting strain in steels.

They find that distortion wedges are characteristic of strain in normal carbon steels, but that they are difficult to observe.

The combined tempering and etching process is the most informative process, but has only been applied successfully to mild steels.

The mechanism of the distortion of normal commercial steels has now been explained in a manner more in accordance with the facts observed than was previously possible. The conception of the distortion wedge is, they believe, novel, and will be, they hope, of value. No attempt has as yet been made to correlate the facts observed with the recent work of Millington and Thompson. Any connection between low temperature thermal,

magnetic, and fatigue critical arrest points; blue brittleness; the critical low temperature annealing which aids the solution of strained areas in the etching of distortion wedges; and possibly abnormal grain growth, have still to be proved.

Steels may show strain-etch figures after heating so as to destroy any blue brittleness.

The subject of strain detection is of importance to steel users, and requires further investigation.

ACKNOWLEDGMENTS.

The authors have been much encouraged by the interest shown in their work by W. H. Patchell, Esq., President of the Institute of Mechanical Engineers; Major S. J. Thompson of Messrs. John Thompson's Water Tube Boilers, Ltd.; and Mr. A. R. Page of the Birmingham Small Arms Co., Ltd.—all of whom have kindly supplied samples of steel. Mr. R. G. Johnston of the Midland Laboratories Guild, Ltd., greatly aided their work by giving facilities for straining all such specimens as were not tested in the University. To these gentlemen, to the head of their own department, Professor T. Turner, and to all others who have aided them, the authors offer their best thanks.

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[The Discussion and Correspondence on this paper will be found on p. 205.]

Iron and Steel Institute.

STRAIN DETECTION IN MILD STEEL
BY SPECIAL ETCHING.

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PART I.

INVESTIGATION OF THE ETCHING PROCESS.

Introduction.

OF the several methods of strain detection already discussed in the paper upon "The Detection of Strain in Mild Steels," by Turner and Jevons, the only one, with the possible exception of X-ray examination, which gave any promise of proving adaptable to practical everyday use appeared to be some etching process such as that originated by Dr. A. Fry of Essen.¹

Part I. of this paper records the results of an investigation by the present author of factors which influence such etching processes, while in Part II. some strain-etch figures obtained by the practical application of such a process are described. It is thought that these figures will prove of great interest to all users of steel in that they have been produced on sections, and do not indicate mere surface phenomena.

The special etching process referred to above was briefly as follows.

Specimens prepared as usual for microscopic or macrographic examination—special care being taken to avoid distortion by vigorous grinding or polishing—are given a short low temperature annealing at a "suitable" temperature; half an hour at 200° C. being suggested. They are then etched in one of the following solutions until the desired result is obtained, which for macrographic etching is usually in five to twenty minutes.

¹ *Stahl und Eisen*, August 11, 1921, vol. xli. p. 1093.

No. 1 Solution. For Macrographic Etching.

120 cubic centimetres concentrated hydrochloric acid.
100 " " water.
90 grammes crystallised copper chloride.

No. 2 Solution. For Microscopic Etching.

40 cubic centimetres concentrated hydrochloric acid.
30 " " water.
25 " " ethyl alcohol.
5 grammes crystallised copper chloride.

In macrographic etching the specimen is rubbed with a rag moistened with solution and dipped in powdered copper chloride. The specimen is dried without rinsing in water, washed in alcohol and again dried. The etched pattern consists of dark and light bands. These bands appear where a disturbance of the crystals has taken place, and it is possible to distinguish under the microscope whether the difference producing the dark lines is due to disintegration of the crystals, deformation of the crystal boundaries, or slipping of the crystal surfaces. These lines have only been obtained on mild steel, and not on all mild steel with the same distinctness.

This process appeared quite simple and straightforward, but after working for six months and examining hundreds of specimens made from very many different steels without obtaining any trace of the desired markings, the author was completely baffled, especially as many of the steels tried were of practically the same chemical composition as those upon which Dr. Fry had obtained good results. Mr. T. H. Turner therefore communicated with Dr. Fry, who very kindly exchanged a sample of his steel for one of the author's. On etching the piece of German boiler plate thus obtained, the author etched out the characteristic markings in less than a minute, showing that the method of etching with which he had so far been unsuccessful was correct for suitable steels. Subsequently, Dr. Fry wrote saying that he had obtained faint markings on the English sample after *twenty hours' immersion*. The longest immersion the author had given specimens was six hours, as after this a thick pasty deposit always formed on the specimen, and the original paper mentioned *twenty minutes* as the maximum time required.

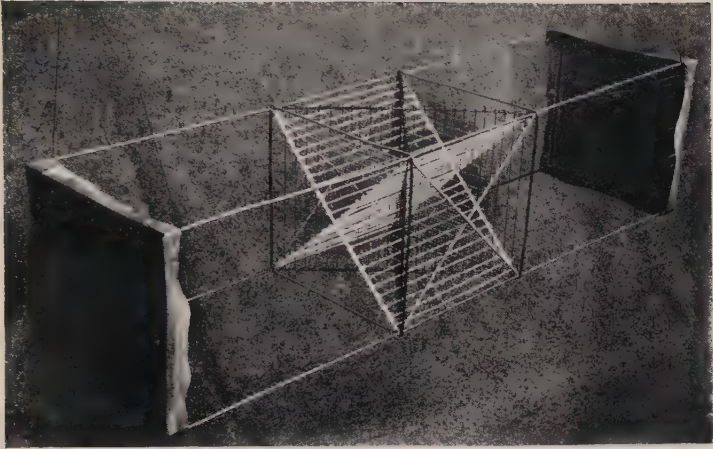


FIG. 11.—Model showing planes on which distortion wedges grow in a bar of rectangular section strained in tension.

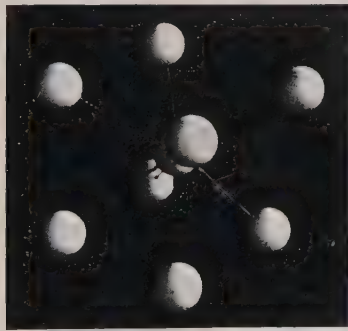


FIG. 12.—Model made by placing a ball wherever six planes intersect in the first model. The skeleton so produced is that of a body-centred cube.

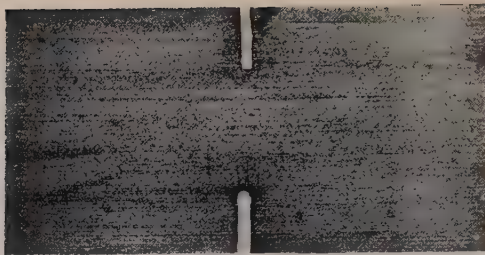


FIG. 13.

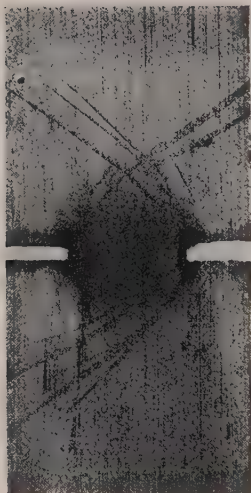


FIG. 14.

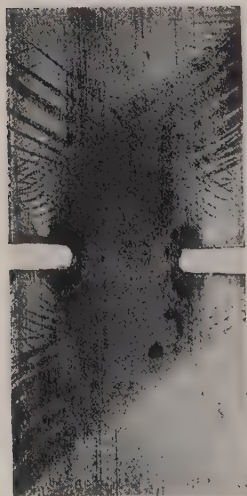


FIG. 15.



FIG. 16.

Flat notched bars, strained in tension to the yield point, $2\frac{1}{2}$, 5 and 10 per cent. (fracture) elongation respectively (on 2 inches), sectioned and etched. (Two-thirds actual size.)

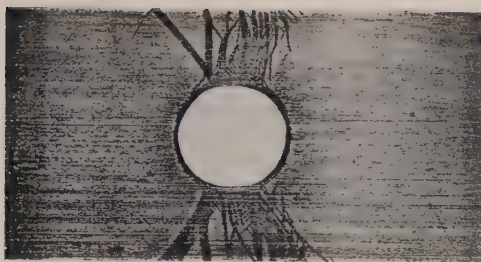


FIG. 17.

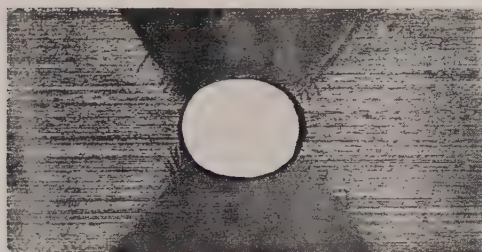


FIG. 18.

Flat bars, with one central hole, strained in tension to the yield point and $2\frac{1}{2}$ per cent. elongation (on 4 inches) respectively, sectioned and etched. (Two-thirds actual size.)

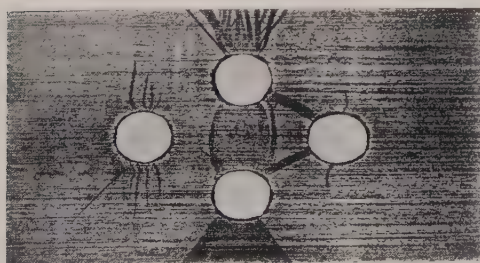


FIG. 19.

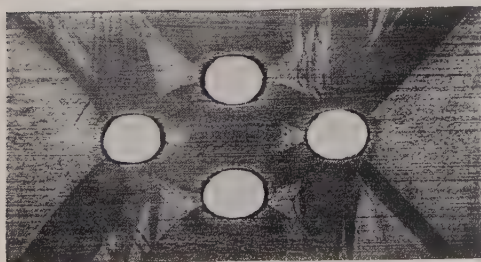


FIG. 20.

Flat bars, with four holes, strained in tension to the yield point and $2\frac{1}{2}$ per cent. elongation (on 4 inches) respectively, sectioned and etched. (Two-thirds actual size.)



FIG. 21.—Flat bar representing screw thread, strained in tension to yield point, sectioned and etched. (Two-thirds actual size.)



FIG. 22.—Flat bar with peg in central hole, strained by loading peg and upper end of bar, sectioned and etched. (Two-thirds actual size.)

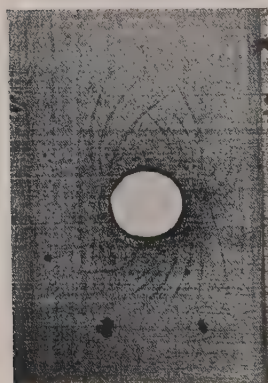


FIG. 23.— $\frac{1}{2}$ -inch D hole in plate enlarged to $\frac{17}{32}$ inch by drifting. Plate sectioned and etched. (Two-thirds actual size.)



FIG. 24.—Cylinder compressed 2 per cent., sectioned and etched. (Two-thirds actual size.)



FIG. 25.



FIG. 26.

Flat notched bars, bent to and slightly beyond the yield point respectively, sectioned and etched. (Two-thirds actual size.)

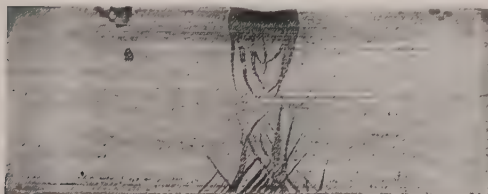


FIG. 27.



FIG. 28.

Flat bars, bent to and slightly beyond the yield point respectively, sectioned and etched. (Two-thirds actual size.)

Specimens of English steel were subjected to a prolonged etching, and after fifteen hours traces of the characteristic markings began to appear, a satisfactory etch being obtained after sixty to eighty hours' immersion. Some steels, however, still failed to give markings after a week's etching, while on others the distinctness of the figures varied considerably, and a careful study of the factors influencing the etching process was therefore made. It should be mentioned that throughout the whole of this paper all remarks refer to macroscopic etching unless otherwise stated.

1. *Type of Steel.*

As just mentioned, it was not found possible to produce strain-etch figures on all steels, and the type of steel upon which markings could be developed was naturally the first subject to be investigated.

General observations gave no indication as to the influence on the etching process of the chemical composition of a steel, beyond the fact that a low carbon content was apparently necessary. Dr. Fry mentioned this in his first paper on strain etching, and put forward the suggestion that a fair amount of phosphorus was an essential constituent of a good strain-etching steel. An attempt was therefore made to obtain some definite information on the matter by making a uniform series of flat notched tensile test-bars from twelve selected steels of different composition, varying from 0.07 to 0.32 per cent. carbon, 0.03 to 0.1 per cent. phosphorus, and different amounts of silicon, sulphur, and manganese. All these bars were strained the same amount (5 per cent. elongation on 2 inches), annealed for three-quarters of an hour at the same temperature (200° C.), and etched in one bath. Four out of the twelve developed no markings at all. A careful comparison of the quality or absence of the markings and the analysis of the corresponding steels gave no hint of any existing connection. The strain-etch figures were good, poor, or entirely absent, quite irrespective of the percentage of phosphorus or any other element.

Steels having marked segregation lines due to rolling do not as a rule give clear strain-etch figures.

To sum up, beyond the fact that a carbon content below about 0.3 per cent. is apparently essential, no connection has yet

been discovered between the chemical composition of steels and their ability to strain-etch satisfactorily, but it is evident that previous heat treatment has a marked influence in this connection.

2. *Composition of Solution.*

Many variations of Dr. Fry's original solution (see p. 192) have been tried.

Meyer and Eichholz¹ have used the following solution, in which the strong acid concentration (present to prevent copper depositing on the etching surface) is replaced by an addition of ferric chloride.

No. 3 Solution.

100	cubic centimetres	water.
80	"	" concentrated hydrochloric acid.
20	grammes	crystallised copper chloride.
20	"	ferric chloride.

They state that they obtain better results with this than with Dr. Fry's original solution, but the latter worker has intimated that he prefers his own formula, as the new solution masks the real strain-etch figures by developing segregation marks to too great an extent. This is confirmed by the experience of the present author, who finds that the strongly acid solution, although decidedly unpleasant to work with, gives the better results.

Very many other etching solutions, with and without colloidal additions, have been experimented with during the last eighteen months, but the peculiar strain-effect figures have never been developed satisfactorily by the present author with any solutions except such as contain copper chloride.

3. *Temperature of Preliminary Annealing.*

Experience had shown that the range of time and temperature for annealing those steels upon which markings could be developed was fairly wide, but some definite information on this point was nevertheless desirable. Accordingly, a series of six flat notched tensile test-bars of similar size and shape was made, and each bar strained to the same extent (5 per cent. elongation on 2 inches). The six bars were then annealed respectively at 100°, 200°, 300°, 400°, 500°, and 600° C. in an electric muffle for three-quarters

¹ *Verein deutscher Eisenhüttenleute*, "Werkstoffs Ausschuss," Bericht 20, 1922.

of an hour, after which they were prepared in the usual manner and etched together in the same bath. Little difference could be detected in the clearness of the markings on the bars annealed at 200°, 300°, and 400° C., but on those annealed at 100° and 500° C. the figures did not develop so quickly, and were, especially on the latter specimen, much fainter, although still perfect in detail. The bar annealed at 600° C. showed only faint traces of strain markings, with imperfect detail. The specimens were made from a typical mild steel, and the results show that for this material a useful annealing range exists between 200° and 400° C., while annealing at 600° C. prevents the formation of satisfactory figures.

4. *Degree of Strain in the Steel.*

General observations suggested that, provided permanent deformation had actually occurred, the degree of distortion in specimens had little influence on the quality of any markings which might be developed by etching.

To confirm this theory two series of flat notched tensile test-bars were made from two different steels. The five bars of one series were strained respectively to the yield point, $2\frac{1}{2}$, 5, $7\frac{1}{2}$, and 10 per cent. (fracture) elongation, all on 2 inches, and the three bars of the other series to the yield point, $7\frac{1}{2}$ and $12\frac{1}{2}$ per cent. (fracture), also on 2 inches. All the bars were then annealed at 200° C. for three-quarters of an hour, prepared as usual, and etched in one bath. No difference could be observed in the quality of the markings on any of the bars in their respective series, although the markings on the bars which had been strained to their yield point took slightly longer to develop.

5. *Time of Etching and Method of Manipulation.*

The length of time during which specimens must be immersed in the etching bath in order to produce satisfactory markings depends on four things—temperature of bath, amount of etching solution per unit area of steel surface, frequency of agitation of bath, and etching properties of the steel undergoing treatment. The effect of temperature is dealt with separately in the next section. With regard to the second factor, plenty of solution is

essential, as it is used up rapidly. During etching the colour of the bath turns from green to brown, and when a deep sepia tone has been attained the rate of etching is so slow as to render a change of solution advisable. Different steels need different amounts of solution, but as a very rough indication the use of a litre of No. 1 solution for every 30 square inches of steel surface exposed may be suggested. If the etching process be carried too far detail is lost, fine markings disappearing completely, although differences in level of as much as a millimetre may be developed on the surface of the specimen after a week's immersion. Using the proportion of solution of steel just mentioned, the author obtains good results in from sixty to eighty hours if the bath be kept well stirred.

With regard to actual manipulation in the process, the author does not find that any improvement results from rubbing the surface of the specimen during etching with powdered copper chloride, as advised by Dr. Fry. Wazau¹ prefers to give specimens a preliminary etching in strong hydrochloric acid for twenty minutes, and then applies the main solution with a brush, as he considers the presence of air beneficial to the etching process.

For the purpose of photographic reproduction of strain markings steels may be divided into two classes: (a) in which there is sufficient contrast between light and dark constituents *when dry* to enable the markings to be photographed directly, and (b) in which artificial contrast has to be produced by deep etching the specimen, allowing it to rust slightly, and polishing the less attacked areas by rubbing on a flat sheet of emery-paper. It may be mentioned here that with practically all steels which develop markings the latter show up very plainly when the specimen is wet, but on drying much of the contrast often disappears. If much reproduction had to be done it would be worth while fitting up a vertical camera to photograph specimens in a bath of clear acid.

6. *Temperature of the Etching Bath.*

It was thought that the time of etching might be shortened by raising the temperature of the bath. Specimens were therefore etched at 30°, 50°, 80°, and 100° C., but it was found that

¹ *Zeitschrift des Vereines deutscher Ingenieure*, 1924, vol. lxviii. p. 1185.

although depth of etching and vigour of attack certainly increased as the temperature of the bath rose, selectivity of action on strained and unstrained metal decreased rapidly. Subsequently, it was stated by Oberhoffer and Toussaint ¹ that by using a bath cooled to 0° C. very fine detail could be brought out in the resulting strain-etch figures, although the time of etching was necessarily prolonged. The author is of opinion that for all ordinary work the best compromise between a fine etching and a reasonable time of immersion is obtained with a bath at room temperature.

7. Preparation and Condition of Surface of Specimen.

This matter has been thoroughly investigated, as in earlier work it was thought that failure to obtain strain-etch figures was due to inability to produce a surface undistorted by polishing operations. Later experiments have shown that, provided reasonable care be taken and a sharp tool used for the preliminary preparation of the surface, no special precautions are necessary. A method successfully used by the author is to finish off a specimen with light cuts from a milling cutter and remove the resulting burnished surface by immersing the specimen for a few minutes in dilute nitric acid. After washing, the specimen may be placed directly in the etching bath. All the tedious operations of filing, grinding, and polishing are eliminated.

SUMMARY.

From the foregoing results it would appear that by subjecting suitably prepared specimens to a preliminary low-temperature annealing, followed by a prolonged etching in certain solutions of copper chloride (see p. 192), strain-etch figures may be produced on many, but not all, steels. Beyond the fact that a fairly low carbon content is apparently essential, no connection has yet been traced between the chemical composition of steels and their ability to strain-etch. Provided that permanent deformation has occurred, the actual degree of distortion has but little influence on the quality of the markings.

¹ *Stahl und Eisen*, 1924, vol. xlv. p. 1330.

PART II.

STRAIN FIGURES PRODUCED IN MILD STEELS.

Introduction.

The figures developed on steel surfaces by the etching process described in Part I. of this paper consist of dark areas and lines composed of permanently deformed metal. By the examination of sections and of the sides of specimens it has been definitely proved that :

1. There is an abrupt change in hardness on crossing any line in the figures dividing light and dark areas. Impressions taken with a 1-millimetre ball as close as possible on either side of a dividing line show a difference of as much as 50 Brinell hardness numbers, the darker or distorted metal always being the harder.
2. The etched lines correspond exactly with any Lüders' lines produced on the surface of the specimen.
3. There is an actual reduction in the cross-sectional area of a specimen wherever these bands occur.
4. The markings produced by etching are really the sides or surface evidence of blocks of permanently deformed metal, which have been named, in the companion paper to this, "distortion wedges."

These wedges are rectangular in section, and although in many specimens they appear as parallel-sided bands, in their incipient stages of development they always appear as slightly tapered wedges. They originate from points of greatest stress, and increase much more rapidly in their length than in their width of base. If the base be straight, as on a rectangular bar, the wedge will grow straight, but if the base be curved, as when the generating point lies on the edge of a round hole, the wedge will be curved.

It may be argued that such strain figures as are shown are of little practical assistance to the engineer and designer, as once permanent deformation has occurred in a piece of metal the system of stresses present therein is at once altered. This, of

course, is perfectly true, but for *small* amounts of deformation the stress system will not vary to a marked extent, and the etched figures may be taken as a fair indication of the stresses present in a specimen, and, in any case, the fact that distortion wedges always start from points of greatest stress should in itself prove of value. When considerable distortion has occurred, discretion must be exercised in relating resulting figures to original stresses.

Strain Figures on the Conventional Flat Tensile Test-Bar.

From time to time the surface phenomena known as Lüders lines have been discussed, and many theories explaining the internal mechanism of the yielding, elongation, and fracture of a tensile test-bar have been put forward, but the author has never seen any of them substantiated by visible evidence, and the photographs contained in Plate XXII. should therefore be of considerable interest. Ten flat tensile test-bars of conventional shape are shown which have been strained, sectioned, and etched. When pulled the bars had a uniform coating of hard mill scale in which very clear Lüders' lines were produced, thus enabling the surface deformation of the bars to be watched closely while elongation was actually taking place. Space does not permit the inclusion of photographs of these Lüders' lines, but on each bar they correspond exactly with the main lines of the etched figures.

The marks caused by the grips of the testing machine are worthy of note, particularly as all visible indentations were machined off the bars before etching. The main strain-etch figures indicate that in no case has truly axial loading been obtained, and not once in the considerable number of tensile specimens examined by the author has this condition been attained.

On every bar permanent deformation as revealed by the scale markings first became apparent at a shoulder in a band running in a direction at right angles to the longitudinal axis of the test-piece. A few similar bands, or, as they were subsequently shown to be, distortion wedges, then formed (Fig. 1, Plate XXII.), followed by additional wedges running at an angle of nearly 45° to the longitudinal axis of the bar (Fig. 2). A network of these transverse and diagonal bands, with a lesser set on the opposite diagonal plane, then spread gradually from the shoulders up the

test-piece (Fig. 3). This process occurred at both ends, and the two systems of bands usually met about two-thirds of the way up the bar (Fig. 4). Soon all traces of individual lines vanished (Fig. 5), distortion wedges having intersected all over the parallel part of the test-piece, and the distorted area spread gradually out into the shoulders of the test-piece, shooting out tangential lines of increasing size (Figs. 6 to 9), until fracture occurred as the result of necking somewhere in the parallel portion of the specimen (Fig. 10). As explained, these scale markings correspond exactly with the real system of distortion wedges as revealed by etching, and shown in the photographs. (See Plate XXII.)

On examination of the etched specimens it was found without exception that if the distortion wedges crossing the surface of the bar at right angles to its length were traced round to the sides of the specimen they ran in a diagonal direction, while those which crossed the surface diagonally were always perpendicular on the sides. From these and other specimens it was evident that distortion wedges always grew along four set planes, as in no case did the inclination of principal wedges to the main axis of the bar depart from these planes by an amount greater than could be accounted for by the physical deformation of the specimen. As a rule wedges formed first on the planes cutting the surfaces of the bar at right angles to its length, next on one diagonal plane, and lastly on the other diagonal plane. The collocation of these planes in relation to the surfaces of a rectangular test-bar is shown by the grey and black threads of the model illustrated in Fig. 11 (Plate XXIII.). Although on account of experimental difficulties no actual proof is available at the time of writing, it seems safe to assume that if, in addition to tension along the longitudinal axes of the bars, tension in a direction at right angles to these axes had also been applied, distortion wedges would have been produced on a fifth and sixth plane, as shown by the white threads in the model.

Present experience indicates that this system of planes holds good for all mild steel bars of rectangular section pulled in tension, but that it is not applicable to round bars and compression test-pieces.

By placing a ball wherever six planes intersect and then removing the latter, the familiar skeleton of the body-centred

cube or iron space lattice is obtained (Fig. 12, Plate XXIII.), and although at present the author is not in a position to put forward any definite theory, it seems very improbable that this marked relationship is mere coincidence.

Examination of Figs. 3, 4, and 5 (Plate XXII.) shows that distortion wedges intersected all over the parallel portion of the bars at between 2.5 and 3 per cent. elongation. Possibly this is connected in some way with the fact observed by Edwards and Pfeil¹ that in a series of their bars maximum abnormal grain growth occurred in the bar elongated 2.75 per cent.

Strain Figures on Flat Tensile Bars of Various Shapes.

(a) *Flat Notched-Bars.*—Plate XXIV. shows a series of flat notched tensile bars of similar size and shape strained respectively to the yield point, $2\frac{1}{2}$, 5, and 10 per cent. (fracture) elongation on 2 inches. The middle portions only of the bars are shown. Attention must be drawn to the small wedges just forming at the apex of the bottom notch in Fig. 13, but otherwise the figures are self-explanatory.

The following is an attempt to reconstruct the process by which the specimens broke, and the same principle may be applied to the elongation of the plain tensile bars described previously.

When a sufficient load has been applied to the bar, small distortion wedges form on the planes at right angles to its length at the points of greatest stress concentration, that is, at the apices of the notches (or at the shoulders in the conventional bars of the previous series). These wedges increase in size, and other wedges form on the same and also on the diagonal planes, and the resulting network thickens until an oval-shaped area of permanently deformed metal extends from notch to notch. As this area grows, and the metal of which it is composed becomes harder and harder through work-hardening, distortion wedges grow along diagonal planes in the main body of the bar (Fig. 14, Plate XXIV.). The presence of more than one wedge on each plane may be explained by the fact that as soon as one wedge forms it becomes work-hardened, and it is therefore easier for further deformation to take place on another parallel plane in the surrounding undistorted

¹ *Journal of the Iron and Steel Institute*, 1924, No. I. p. 128.

metal than in the hardened wedge. The new wedge immediately hardens, and the process is repeated till the main parts of the bar become sufficiently hard again to transmit stress to the central area, when the whole series of phenomena are repeated. Ultimately the central area becomes so reduced in cross-sectional area that it is unable to withstand the stress to which it is subjected and rupture occurs. The elongation of the central deformed area necessitates adjustment at the boundary line between itself and the surrounding undeformed metal, and this results in the formation of the smaller, curved, and often intersecting wedges. If the elongation process be considered carefully, bearing in mind the fact that the surrounding metal is undistorted and therefore stationary, while the central area is continually elongating, it is easy to see how these wedges become curved. A similar effect occurs in a few instances at the boundary between a large primary distortion wedge and the surrounding metal.

(b) *Tensile Bars with Screw Thread*.—Some flat bars with edges shaped to represent a screw thread were pulled in tension. Fig. 21 (Plate XXVI.) shows the figure produced by straining one of these to the yield point. As would be anticipated, the greatest stress concentration occurs at the bottom of the notches, but it is interesting to observe that points of equally intense concentration exist where both the last notch and the round shoulder join the parallel part of the bar.

(c) *Tensile Bars with One Central Hole*.—Figs. 17 and 18 (Plate XXV.) show flat bars of this type strained respectively to just beyond the yield point and to $2\frac{1}{2}$ per cent. elongation on 2 inches. It will be seen that the main diagonal distortion wedges in Fig. 17 and the edges of the deformed areas in Fig. 18 are at the same angle of inclination to the longitudinal axis of the bar.

(d) *Flat Tensile Bars with Four Holes*.—The figures produced by straining bars of the type illustrated to the yield point, and to $2\frac{1}{2}$ per cent. elongation on 4 inches, are shown in Figs. 19 and 20 (Plate XXV.) respectively. Curved boundaries such as can be seen between the four holes in Fig. 20 are unusual. The latter figure is somewhat suggestive of the strain pictures produced by Dr. Coker in his photo-elasticity experiments. The points of original maximum stress concentration may be easily deduced from Fig. 19.

(e) *Flat Tensile Bars with Tight Peg*.—In these specimens a peg

was turned down to a driving fit in the central hole of the bar, forced in, and load applied to the peg and one end of the bar. The figure shown in Fig. 22 (Plate XXVI.) is produced by straining such a specimen just beyond its yield point. Similar specimens having a loose peg gave very similar strain figures.

Strain Figures on Bend Specimens.

A number of bend specimens, both plain and having different types of notches on one side, have been examined. Each specimen was supported at the ends and prevented from twisting by heavy blocks slotted to receive it, and a $\frac{3}{4}$ inch diameter roller was forced down on its upper edge directly over the notch. Plain slots, sharp grooves, and Charpy type notches gave practically identical figures, of which those shown in Figs. 25 and 26 (Plate XXVII.) are typical. Fig. 25 shows a specimen strained just beyond its yield point, and in this and other notched-bend pieces it is interesting to observe that in all cases wedges start from the *sides* of the notch and not from the apex, and that deformation of the bar always occurs first underneath the roller on the side remote from the notch. Such specimens may, however, give different results when strained by impact. Fig. 27 (Plate XXVII.) shows a plain bar bent just beyond its yield point, and Fig. 28 a similar bar bent somewhat more. In the latter, the existence of a neutral axis is demonstrated very clearly.

Strain Figures Produced by Drifting.

Holes drilled in a steel plate were enlarged by having a hardened steel peg, tapered 0.025 inch per inch, forced into them by repeated blows, the plate being supported meanwhile on a flat surface, having a hole just large enough to receive the peg. Fig. 23 (Plate XXVI.) shows the strain figure produced by enlarging a $\frac{1}{2}$ inch diameter hole to $\frac{1\frac{7}{8}}{2}$ inch by this method, and bears a marked resemblance to the figure produced by a Brinell impression.

Strain Figures on Compression Cylinders.

At the time of writing very little work has been done on specimens subjected to compressive stresses, but as a matter of interest

Fig. 24 (Plate XXVI.) has been included. It shows the figure produced on a sectioned steel compression cylinder, of the shape shown, which has been compressed 2 per cent. of its total height. The difference of inclination to the longitudinal axis of the cylinder of the thin distortion wedges and the edges bounding the central deformed area is particularly interesting, and in the near future the author hopes to examine these and similar specimens, with a view to correlating any results obtained with the slipping cone theory of Riedel.¹

CONCLUSION.

From the foregoing examples it will be seen that this special etching process is capable of yielding highly interesting results, and that its range of application is extensive. In its present form it is subjected to the very considerable disadvantage that strain-etch figures cannot be produced on all steels, and its usefulness in the examination of actual failures is therefore limited, but, even so, it seems probable that at the present time a designer could obtain valuable information by constructing models from steel upon which it is known that satisfactory markings can be produced, straining and etching them. By suitable modifications to the process it may soon be possible to produce markings on all steels, in which event its already considerable value would be greatly enhanced.

ACKNOWLEDGMENTS.

The author wishes to express his thanks to Professor T. Turner of the Metallurgical Department, University of Birmingham, in whose laboratory the work was carried out; to Mr. T. H. Turner for his keen interest and valuable assistance; and to those gentlemen who by their kindness in supplying samples of steel have materially assisted the research. His special thanks are also due to Mr. R. G. Johnston, of the Midland Laboratory Guild, Ltd., for his interest and kind permission to use his testing machine for the straining of specimens.

¹ *Stahl und Eisen*, 1917, vol. xxxvii. p. 1133.

DISCUSSION.

Dr. WALTER ROSENHAIN, F.R.S. (National Physical Laboratory), in opening the discussion said the authors had presented the meeting with a very interesting series of photographs which showed a successful application of Fry's method of etching material previously strained. He felt, however, that the most interesting fact they showed was that some steels etched in that way and others did not, but unfortunately they could not yet tell why. That was possibly a matter of greater interest than any other which they had raised.

So far as he could gather the meaning of the new term "distortion wedges" correctly, he understood it to imply that distortion started from a point of maximum strain or maximum stress, where plastic deformation commenced and spread along the lines which were shown on the photographs, in which the width of the distortion region was seen gradually tailing off as the point where deformation had begun receded. He was not sure if that was precisely what was meant. The language of the paper was open to the interpretation that the "distortion wedge" was the triangular mass of metal between those lines.

Mr. TURNER said that what they had in view was that the distorted part of the metal actually advanced across the specimen. The word "plane" did not accurately explain it; it really was a wedge of distortion which gradually moved across the specimen.

Dr. ROSENHAIN said that was useful, but he ventured to think it was not quite as novel as the authors seemed to suggest. He was not quite sure whether he had seen it in the literature, but no doubt many of them were familiar with the gradual progression of plastic deformation. For instance, with regard to the Lüders' lines, it was well known that they did not appear simultaneously right across the width of a test-piece. Nevertheless, the demonstration which the authors had given was interesting and the photographs were very beautiful.

He was afraid he could not see how the fact that they had the six diagonal planes of the cube occurring in such strains could have anything to do with the fact that iron had a body-centred lattice. He thought it was extremely likely that other metals having a different lattice showed a similar type of distortion. He thought all that was happening, as Mr. Turner suggested, was that there was a certain geometrical coincidence arising from the shape of the test-piece, which led to a geometrical configuration in the strains, which was also one of the simple forms of symmetry which occurred in the body-centred lattice. Another

very interesting fact—although not of course new, but still very interesting in connection with such matters—was the circumstance that in order to get those etching figures it was necessary, first of all, to subject the strained material to a certain amount of heat, somewhere about 200°C . That was a striking fact, because it was just that amount of heat which removed some of the most characteristic mechanical effects of plastic deformation. If a piece of mild steel were strained beyond the yield point and examined afterwards, it would be found that it had a peculiar lack of elasticity, but if it were heated to 200°C . for two minutes that lack of elasticity disappeared and it appeared as a work-hardened steel having a reasonable elastic behaviour. Whilst the material was in the "semi-plastic" condition immediately following strain, the Fry etching process would not work. Heating to 200°C . caused recovery of elasticity and also brought about that property of etching. He wished to ask the authors if they had ever given the sample a period of prolonged rest at the ordinary temperature, and if they could say whether or not after that prolonged rest such strain etching could be obtained. It was a matter of very considerable interest.

Further, as possibly throwing some light on the question of the behaviour of different materials, he would like to point out that the time and temperature required for bringing about the elastic recovery varied widely with the purity of the material, and it might be there was a factor of the same kind at work in determining whether or not those lines could be obtained.

There could be no doubt whatever that the whole subject was one of considerable interest, because, whilst it was necessary to study the mechanism of strain on a much more minute scale, there was a good deal of interest in knowing about such a process. The lines in the authors' photographs were in reality very similar indeed to the optical figures obtained by Professor Coker's method, and that in itself was interesting. Those results obtained on such amorphous materials as xylonite and glass, provided the deformations were not large, did not differ very greatly from those which were to be found in steel.

Mr. C. E. STROMEYER, O.B.E., M.I.Mech.E. (Manchester), said he had brought with him a few samples which might prove of interest. A piece of steel which had been picked up from a scrap-heap had been etched according to the Fry system and had given satisfactory results. To his mind it was a rather good specimen, for the lines were as fine as pencil marks. They were not of the broad-band impressionist style. One of the samples in which a hole was punched in the centre of the plate showed beautiful logarithmic lines which crossed each other. The other specimens showed the lines produced by shearing off the edge of the plate. The latter samples had not been heated in an oven: they had been ground on an emery-wheel so as to get a smooth surface, and he fancied they must have been heated during that operation to a considerable temperature, which at once produced the effect which was

necessary with the Fry process, and he wondered whether it would not be interesting to study the question as to the time of heating. One of the papers which had just been read mentioned that all the samples had been heated for about half an hour. His samples could not have been heated for more than a few minutes. The lines were numerous and very marked at the sheared edge of the plates, and disappeared further on, as if the plates had been more severely heated at the edge than elsewhere, showing that a comparatively short exposure to high temperature produced the condition in which the Fry etching would show such lines. He then tried another piece of steel which had not been picked up from the scrap-heap; he strained it, but could not get any lines at all. In those samples he noticed other markings which evidently had nothing to do with the straining of the material—at least, not a straining of the material as ordinarily understood, but straining perhaps during the rolling process. Those markings were also visible on the samples from the scrap-heap. They looked like wood grain. In fact, having traced a few lines he found that they were practically contours. They had the appearance of being the intersection of the outer planed surface through a number of fine layers of metal which were parallel to the original outside surface of the sample as rolled, and, as that outside surface was naturally irregular, the lines represented the contours due to the depressions and risings of the surface. According to a rough estimate on one of the samples, the thicknesses of the layers were of the order of two thousand per inch. He could give no explanation as to how those layers were produced, but he would like to suggest a possibility, and that was that some materials—and he would include some steels—behaved during the rolling process like ordinary fluids. When subjected to shearing stresses during the rolling process, the rolls produced a horizontal differential movement in the metal. If the metal were of the nature of a fluid, that movement would be a uniform flow or shear, and the shearing strain would be uniformly distributed. On the other hand, in a metal of a semi-solid constitution the shearing effect would be of a double nature, as if there were friction of rest and friction of movement. Along those surfaces where the friction of rest had been overcome there would be a gliding motion, while the intervening layers would merely flow. Those two different movements might produce a permanent effect which was revealed by the Fry etching process as contour lines. The movements would be of a stepwise nature, shear and flow alternating in successive layers. He was not putting that view forward as an explanation of the phenomena, but he was suggesting the possibility that it might be an explanation.

Naturally he had tried other qualities of steel, and in some specimens which would not show the Fry straining effect at all he nevertheless got contour markings very strongly, but in others he did not get them at all. He also ground and etched round bars, his idea being that the rolling process was the same as in a plate and that similar contour markings

ought to appear, but there was absolutely no effect whatever in regard to the particular steel he used. The markings were certainly a very striking feature of some steels, and he thought the subject well worthy of the most careful study.

He had also come across yet another curiosity. Fry in his publications mentioned that a sample which had been subjected to fatigue torsion stress showed radial lines—apparently the same action which he had suggested as occurring in rolled plates: alternations of friction of rest and of movement. The spoke-like portions between the radial, wedge-shaped lines on the bar sections seemed to have remained unchanged, the shearing movements occurring only in the wedge-shaped lines. When he tried to obtain the same result, but by static torsion instead of fatigue torsion, he obtained a pattern as if the bar had behaved like a rope of five or six strands, shearing, as revealed by the Fry etching, taking place only between the strands. He did not know whether the differences between his results and Fry's were due to the material or to the fact that in Fry's case the stresses were fatigue stresses, and therefore alternately in opposite directions, whereas in his own case they were static stresses in one direction.

[The samples were handed round for inspection.]

Naturally he was very much interested in the question of finding a test which would show the amount of straining to which the material had been subjected. Fry's method apparently afforded means for showing it, but it did not apply to all steels, and it occurred to him that there was a line of research which might prove extremely fruitful if they looked on the etching process from a point of view suggested by the Fry results. The ordinary etching process as practised up to now had been based on the principal that a little acid was added to pure water. Pure water would not attack iron at all, but by adding a little acid a fluid was obtained which would show up the grain of the material. Some concentrated acids behaved like pure water in that they would not attack steel at all, but small quantities of added water constituted the attacking agent. That seemed to him to be the essence of the Fry process, and apparently that attack differentiated between the strained and the unstrained portions of the material, and could be revealed if copper salts were included in the fluids. He had tried to work out that idea by using various concentrated fluids and adding a little water to them, and copper and other salts, but as yet the results had been unsatisfactory. He thought, however, there was a good deal in the idea of trying to work from the strong acid end of the scale as against the strong water end as in the ordinary etching process.

There was an intermediate process of which he had only faint hopes of success, but possibly it might work, as it certainly did when heating steel in air and obtaining colour effects. That was the use of gaseous reagents—for instance, oxygen, chlorine gas, and other gases, and also sulphur dioxide. It was usually believed that sulphur dioxide would not attack iron, but if the iron were heated to 700° or 800° C. it would be

attacked very seriously. As a matter of fact, they had already had a few instances in the case of boilers where fuel containing a large percentage of sulphur had attacked the steel boiler plates very seriously, and it seemed to him, therefore, they had three processes: (1) Using water with a little acid; (2) using strong acid with little water; and (3) using a gaseous reagent like oxygen, sulphur dioxide, or chlorine, which would attack the material generally; and possibly, by juggling with those things as chemists often could do, they might arrive in the future at some test which would distinguish between one condition and another.

(*Added written note.*) Mr. Stromeyer had found that the Fry etching process was very materially improved by dipping the etched samples into strong hydrochloric acid. By that means any deposited copper and any copper solution was entirely washed away without any injury to the etchings. The sample could then be washed in water without suffering injury.

Mr. W. H. PATCHELL (London) said his interest in the papers was from another angle. The authors of the papers had thanked him for encouraging them in their work. He had come to the meeting to encourage them still further, and to express his indebtedness to them for getting on with it.

In connection with the working up of steel by boiler manufacturers, some ready means of testing the steel when it was delivered was much wanted. Boiler plates made by manufacturers of the highest reputation would sometimes fail unaccountably. He was interested in a number of boilers working at 400-lbs. pressure, and also one boiler working at 1200-lbs. pressure. The drum-plates of the boilers working at a pressure of 400 lbs. were 2 inches thick, so the longitudinal seams called for a rivet 6 inches long. That was the sort of thing it was desired to get away from. The boiler drum working at 1200-lbs. pressure had no joint; it was 30 feet long and 4 feet in diameter, forged from a steel ingot. Such apparatus was enormously heavy and expensive, and until they could get some way of readily testing the steel which was supplied to them as a finished article, they were somewhat nervous. When he came home from America he brought back with him Fry's prescription, but unfortunately, in copying it out, the decimal point slipped up. He gave it to Mr. Turner, who found it would not work. Possibly it was somewhat like the one Mr. Stromeyer had mentioned, and one solution was required for one steel and another solution for another. He had also brought home from America, and had since lent to Mr. Turner, a specimen tube from Dr. P. Bridgeman of Harvard, a $\frac{1}{2}$ -inch steel tube with $1\frac{1}{4}$ inch walls, which had been burst by some enormously heavy pressure, and he thought that if Fry's system would show strains, that tube afforded an opportunity. Mr. Turner was still looking for those strains, and he hoped some day he would be able to find them!

Dr. W. H. HATFIELD (Sheffield) congratulated the authors on a very excellent piece of work. He was watching with interest what they would make of it. They were undoubtedly engaged on an extremely interesting subject.

He could not say, with regard to Mr. Patchell's remarks, whether a method of the kind suggested could be devised without making still more difficult the arduous task of the steel-maker. He would, however, point out that where such a method could conceivably be adopted for the disclosing of strain—for instance, in boiler plates—it would be valuable as indicating to the boiler constructor the crudity which was often displayed in the production of boilers from the steel. It was undoubtedly a very important point he was dealing with, because he had on occasions, both at Institute meetings and elsewhere, listened to very subtle deductions based on micrographs at very high magnification, and put forward as evidence to show why boilers had burst. In his opinion, very often the trouble with boilers was really of a very simple kind. The distortion round the holes was often very serious, and minor defects and cracks were left by the boiler-maker's crude methods in the neighbourhood of those holes, and therefore, obviously, if a method such as had been suggested could be employed for the careful examination of the steel in the vicinity of such rivet holes and analogous directions, it would be of great value. He ventured to say, however, whilst they must all be extremely interested in it, and give due credit to the authors of the papers for the explanation they had given of Fry's work, yet they must of necessity wait a little. One very interesting feature they brought out in the papers, with regard to which he agreed, was that the maximum etching effect appeared to be coincident with the critical amount of cold work which produced grain growth. That he thought was a very important matter. When he looked at the test-pieces that had been shown, he naturally anticipated finding an increasingly dark etching where they had an increase of strain, but he did not find it. That was no doubt explained by the fact that the maximum etching effect was coincident with the amount of work, which was not the maximum, but the apparently critical amount of work, which caused grain growth.

He considered the whole subject teemed with interest, and he would look forward with the greatest interest to the authors' further investigations. He was more interested in the matter having regard to the fact that he also very greatly felt the necessity of exploring the subject.

Professor C. H. DESCH, F.R.S. (Member of Council, Sheffield), said he was very much interested in the two papers, because when Dr. Fry's original paper appeared he had personally made many efforts to repeat his results, and had failed in every case to obtain any of those lines. Etching was not continued for much more than twenty minutes, and it was evident the difference was due to a difference in the steels. He admitted he had not been as persevering as the authors had been, and

he had not followed up the process of etching. It would be interesting to know what was the real difference between Fry's steels and the steels which had been examined by the authors. Their series of steels, made up for testing the influence of chemical composition, had been analysed for the ordinary elements present, but not for oxygen and nitrogen, and it was quite possible that the differences in those elements might have something to do with the very remarkable differences between the German and the English boiler steels.

With regard to the reference in Mr. Jevons' paper to the distortion wedges crossing one surface of the bar at right angles to its length in one case, and in the other in a diagonal direction, he thought perhaps they had overlooked the paper by Mr. Adcock which had been read before the Institute of Metals a few years ago, in which he described that arrangement. The form of the wedges had been described in some of the earliest papers on the subject. In Mr. Adcock's work it would be found that those directions were also the directions in which recrystallisation began when subsequent annealing was started, the lines which ran diagonally to the specimen always giving rows of new crystals at a much earlier period in annealing than those which ran parallel with the specimen. Both sets of lines were clearly shown in the process of etching. He thought that might probably have some bearing on the very interesting results the authors had obtained.

Mr. H. O'NEILL (Manchester University) said that Dr. Rosenhain had suggested that ageing might have affected the results. The specimens of metal which Mr. Stromeyer had recovered from the scrap-heap had probably suffered some sort of ageing treatment since being cold-worked. It appeared to him to be very likely that those pieces had been lying about for some time, and had perhaps partly recovered their elasticity. If that were so, then the fact that Mr. Stromeyer had found that less heat treatment was required might lend support to Dr. Rosenhain's suggestion.

Mr. T. H. TURNER, in reply, said it was just possible that the metals which Mr. Stromeyer had produced from the scrap-heap were scraps of metal which had been in service in superheated steam, and that might have given the results which were found.

With regard to the question of time, recent work done by himself and Mr. Jevons had shown that five minutes was enough. A similar example to that shown in Fig. 11 (Plate XX.) had been repeatedly and simply heated at one end for two or three minutes with a blowpipe, and the marks still appeared on etching. With one sample he had made a series of seven Brinell marks, and he calculated the steel at red heat in the flame would be about $700^{\circ}\text{C}.$, and at the bottom in water at the ordinary room temperature. There was one Brinell mark for every 100° of the 700° , and the figures hence etched out at the part which had been heated to about $200^{\circ}\text{C}.$ The sample shown in Fig. 11 had

been heated for longer, but since then he had repeated the same work with only five minutes' heating.

He and his colleague would be much interested to hear more of the work Dr. Hatfield had referred to. They were also very grateful to Professor Desch for pointing out the work by Mr. Adcock. They had overlooked that particular work, but it was not on steel. They had gone into a good deal of non-ferrous work, and certain lines were to be seen, but they had not yet encountered them in the same way as on steel.

The historical references to wedge-shaped marks were undoubtedly very numerous, and he and Mr. Jevons had tried to record in the bibliography at the end of the paper all they could find. It was really extraordinary how much Colonel Hartmann in particular (in the many papers he had written in French, and in the little book, *Distribution des Déformations dans les Métaux soumis à des Efforts*, which Mr. Gulliver had been kind enough to lend the authors) had been able to show by simply examining the surface marks. At that time, of course, one could only deduce from the surface markings what had happened inside the piece of steel, but now they were able to prove that such markings on the surface had nothing to do with the scale, as had been suggested, but really indicated fundamental deformations in the steel.

CORRESPONDENCE.

The AUTHORS wrote, in a final reply, that they failed to see the similarity mentioned by Dr. Rosenhain between the lines in their photographs and the optical figures obtained by Professor Coker. Indeed, the optical method, so far as they were aware, never showed lines, but only areas bounded by colour differences and shaped somewhat like the figures produced by the machining method which the authors had shown on Plates XVIII. and XIX. of the joint paper.

They thought the production of strained wedges of the steel, which projected far from the focus of maximum stress, was clearly shown in their papers, but unknown so far as the optical method was concerned. The photo-elastic method of locating stress concentrations was vastly interesting and most valuable, but their papers showed that discretion must be used in applying its results directly to steel.

Markings similar to the "contour lines" mentioned by Mr. Stromeyer had also been observed by the authors, who had not, however, produced them under controlled conditions. They could, therefore, only add in that respect that such "contour lines" were probably due, as suggested, to the previous rolling or forging operations.

Mr. Stromeyer touched upon a most important point in his remarks upon the influence of the strength of the etching solution. They had found it possible to obtain results with undiluted "commercial" HCl,

or with pure analytical HCl diluted to about half its original strength. The cost of the acid used worked out at about the same figure either way, and their experience was that the pure acid gave less trouble.

They thanked Mr. Stromeyer for the suggestion that gaseous reagents might be worth trying; so far only gaseous HCl had been tried, as mentioned in the joint paper, but they now hoped to try other gases.

With regard to the note which Mr. Stromeyer had later added, it was their regular practice to finish off the etching process by washing in HCl—a point which they were sorry to see had only been indirectly mentioned on p. 196 of the second paper. Such washing in clear acid had generally been followed in their own practice by a wash in methylated spirit. Specimens finally laid in dilute ammonium hydrate had retained their clearness, without rusting, for a considerable time, and that practice might prove useful.

With regard to Professor Desch's contribution to the discussion, the had now referred once more to Mr. Adcock's Institute of Metals paper of 1922, and noted that all his photographs were taken at considerable magnifications, and that he did not apparently show any macro-etch-line phenomena comparable with those shown in Mr. Jevons' paper.

Feeling that the subject of strain detection in metals was of considerable importance, they proposed to continue working upon that subject, and would therefore welcome any further contributions to their knowledge of the phenomena concerned which might be made by members not present at the reading of the papers. They thanked those who had taken part in the discussion for the assistance they had given them.

Iron and Steel Institute.

THE INFLUENCE OF GASES AT HIGH TEMPERATURES UPON IRON, WITH SPECIAL REFERENCE TO THE FORMATION OF BLOWHOLES.

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INTRODUCTION.

PRIMARILY this investigation was undertaken to test experimentally McCance's ⁽¹⁾ explanation of the formation of blowholes in iron and steel. This explanation is based on the assumption that whilst carbon monoxide is easily soluble in solid steel, carbon dioxide is very much less soluble. Both gases are assumed to be soluble in the liquid metal; hence on solidification the carbon dioxide would be expelled, forming blowholes. If McCance be correct, it offers an explanation of the effect of the treatment in the open-hearth furnace on the steel, and its importance is therefore obvious. While attributing the formation of blowholes entirely to carbon dioxide, McCance explains the presence of other gases in the blowholes by assuming their diffusion from the steel into the already formed cavities.

Previous work on the subject of gases in steel has dealt chiefly with the solubility at low temperatures and in the solid state; it has been very completely summarised by Allemann and Darlington, ⁽²⁾ and also by Hadfield ⁽³⁾; therefore in the present paper no attempt is made to include a complete bibliography of the effect of gases on iron.

The experimental method adopted was to melt pure iron in a stream of gas, cool in the same atmosphere, and examine in various ways the specimen obtained. After consideration of different types of furnaces, it was decided that the most suitable one for the purpose was an electric furnace, using a carbon tube resistor of the type originated by Hutton and Patterson. ⁽⁴⁾ Accordingly, a vertical furnace was designed and built, a large

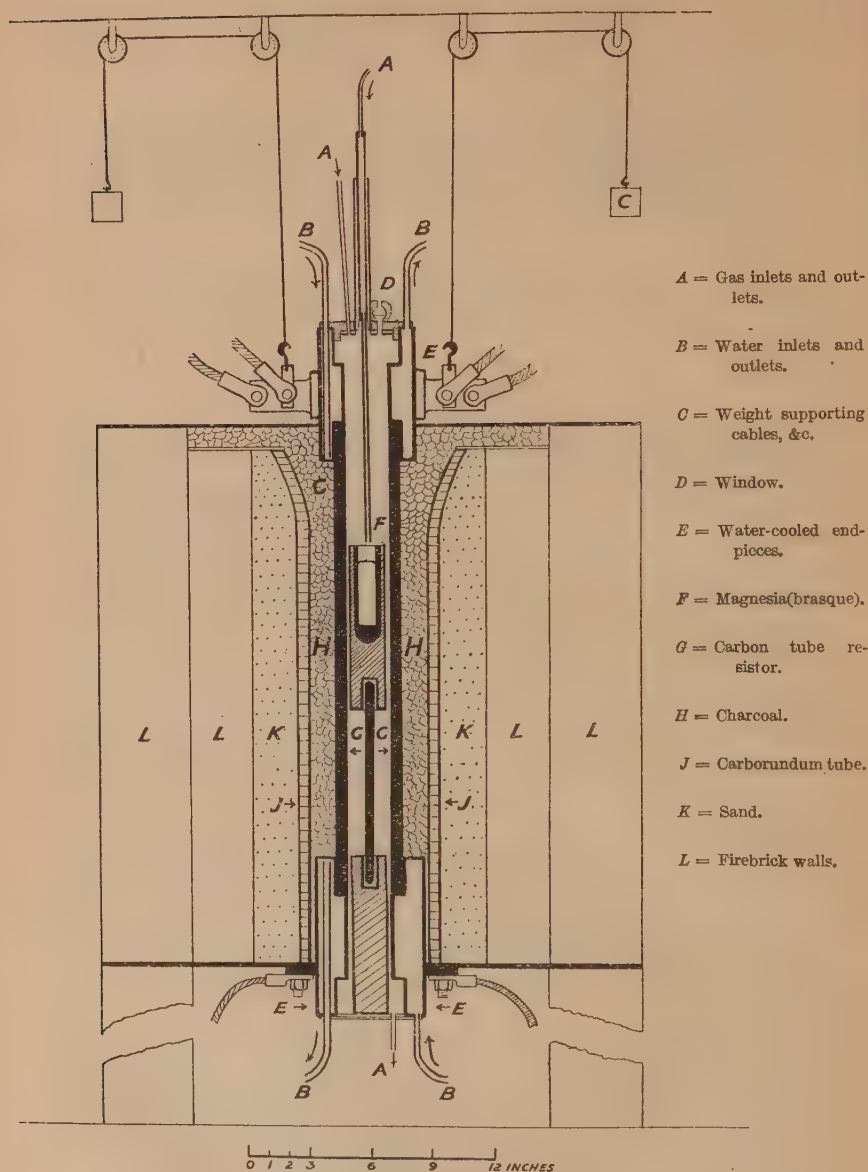


FIG. 1.

carbon tube, 3 inches in diameter, being mounted in gun-metal water-cooled end-pieces. The diagram (Fig. 1), giving a sectional elevation of the furnace, shows the construction sufficiently clearly for the purposes of this paper without further description. The crucibles were turned out of solid graphite and lined with a brasque of fused magnesia, using a binder of magnesium chloride.

Armco iron was considered to be sufficiently pure for the purposes of this investigation, and was used in the form of round bar, cut off in lengths to suit the crucible.

The gases used in the work were hydrogen, nitrogen, carbon monoxide, carbon dioxide, and coal-gas. The carbon monoxide was prepared by passing carbon dioxide over heated charcoal, excess carbon dioxide being removed in the usual way. All the gases were dried before use, any oxygen in the nitrogen being removed by means of an alkaline pyrogallol solution. The gas was passed into the furnace through the top tube, which was arranged so that the gas impinged on the surface of the metal before passing to other parts of the furnace. Positive pressure was maintained in order to minimise diffusion inwards through the carbon tube. A small secondary flow of gas was directed into the upper part of the tube to remove fumes and so facilitate observation.

Observations were made through the window in the top, this being specially devised to enable both sides of the glass to be cleaned during the actual experiment. The temperature was measured by means of a Wanner optical pyrometer, which was calibrated from time to time. By careful regulation of the electrical energy supplied to the furnace the temperature was raised and lowered at a definite rate, the maximum temperature in each experiment being maintained for thirty minutes. Fig. 2 illustrates graphically the course of a typical experiment.

For the purpose of checking McCance's assumptions, it was only essential to heat the metal to a temperature similar to that prevailing in the open-hearth process; the opportunity, however, was taken of making a series of observations at higher temperatures, up to over 2000°C. , both with carbon monoxide and carbon dioxide.

The crucible, with its charge of metal, about 300 grammes, was placed in the centre of the furnace tube. After passing

the gas for a sufficient length of time to ensure the air being completely displaced (confirmed by tests) the furnace was started up, the rate of heating and cooling being standardised, as already stated. The melt was allowed to cool completely in the stream of gas before removal from the furnace.

After visual examination of the treated metal the apparent

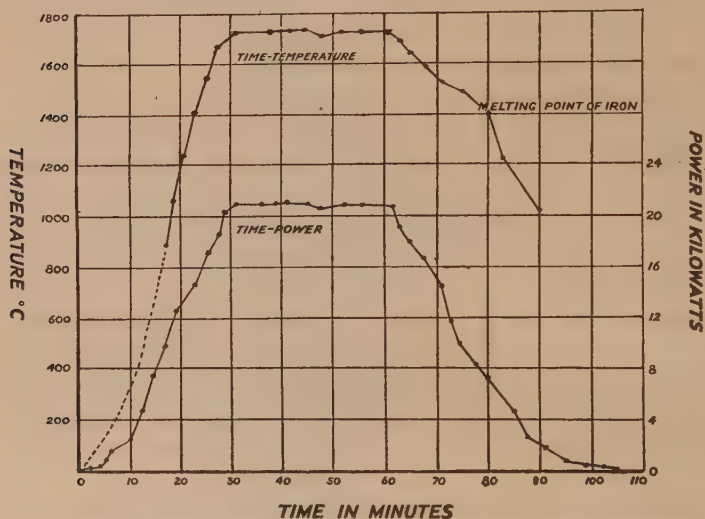


Fig. 2.—Typical Experimental Curves Illustrating Rates of Heating and Cooling.

density was determined, from which the volume of the blowholes was calculated. The planimetric method of measuring the capacity of the blowholes, as used by Czocharlski,⁽⁵⁾ did not offer any prospect of success in this instance, owing to their irregular shape and distribution. The specimens were then cut longitudinally, one-half of each being ground, polished, and etched for micrographic examination (alcoholic picric being found to give the best results). The same halves were subsequently finely reground, and etched with 20 per cent. sulphuric acid for macrographic examination. On the remaining halves the Brinell hardness was measured, the mean of three determinations on each specimen being taken. Tensile tests were made on a number of the samples, the results of these being referred to at the end of this paper.

The main results are shown in the table (p. 220). The blow-

hole capacity with the gases carbon monoxide and carbon dioxide over a range of temperature, and the Brinell hardness

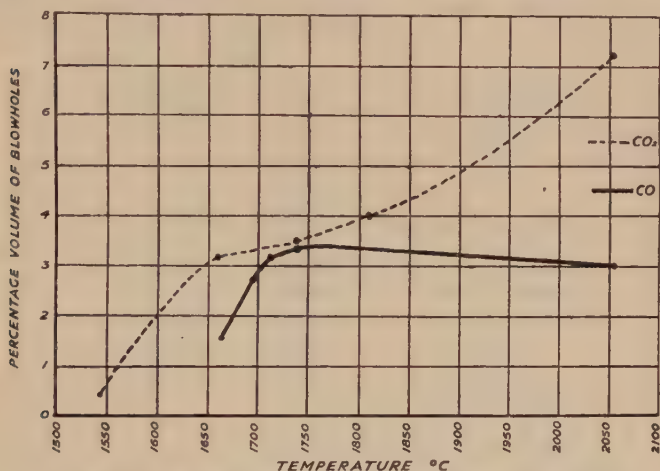


FIG. 3.—Blowhole Volume/Temperature Curves with Carbon Monoxide and Carbon Dioxide.

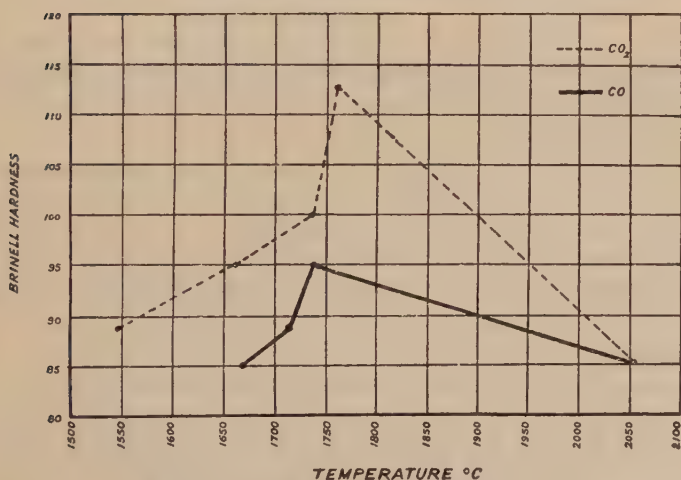


FIG. 4.—Brinell Hardness/Temperature Curves.*

numbers for the same specimens, are depicted graphically in Figs. 3 and 4.

* The top point on the dotted curve (CO₂) in the lower diagram is marked 50° too low. It should be 1810°, not 1760°.

TABLE I.

Experiment Number.	Gas, &c. (Fig. 3).	Temperature °C. (Fig. 3).	Volume of Blowholes. Per Cent.	Brinell Hardness Number.
20	CO ₂	1546	0·46	89
10	"	1657	3·20	95
12	"	1737	3·55	100
27	"	1810	4·00	113
23	"	2054	7·20	85
29	CO	1666	1·66	85
2	"	1694	2·78	122
28	"	1715	3·24	89
13	"	1737	3·39	95
33	"	2054	3·06	85
9	CO + Fe ₂ O ₃ *	1694	5·19	89
5	N ₂	1700	0·64	89
8	H ₂	1694	13·14	129
6	Coal-gas	1700	2·63	107
15	"	1737	8·24	89
7	Coal-gas + Fe ₂ O ₃ *	1694	4·99	85
16	" "	1680	4·02	95

* The iron oxide was introduced in the form of Fe₂O₃, but at the high temperatures would be transformed, first into the magnetic oxide and further into FeO.

Notes.—Experiment 20. In this the temperature was not sufficiently above the melting point to bring about absorption of the gas in excess of the solubility in the solid state during the time exposed.

Experiments 2, 8, 15, and 27. The specimens were appreciably carburised, 0·2 to 0·3 per cent. ; but in all the other experiments the structure was that of a very mild steel.

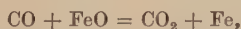
Experiment 5. The soundness of the melt with nitrogen was confirmed by other experiments, which, however, are not given here, owing to the failure of the brasque causing carburisation.

A very large grain-size was observed, from 0·25 millimetre to 0·40 millimetre, in the carbon dioxide series, and somewhat larger, 0·27 millimetre to 0·45 millimetre, in the carbon monoxide treated specimens, in both cases the size increasing with the temperature.

These results show that :

1. The blowholes occupied a greater volume in the carbon dioxide treated specimens than in those subjected to carbon monoxide at corresponding temperatures.

2. The blowhole volume increases with the temperature; this is probably due to the increased solubility of gases at higher temperatures, the subsequent rate of cooling not being slow enough to allow the excess gas to escape before solidification.
3. The Brinell hardness numbers for the carbon dioxide series are higher than for the carbon monoxide experiments, with the exception of experiment No. 2, in which the greater hardness is accounted for by carburisation. This result is omitted from the hardness graph.
4. The rate of crystal growth appears to be greater with carbon monoxide than with carbon dioxide, the resulting larger grain-size accounting, in part, for the reduced hardness in the former series.
5. In general, hardness varies with the temperature, in the same sense as the blowhole volume.
6. The density determinations of blowholes were confirmed by the appearance of the specimens when cut. See Plates XXVIII. to XXX., showing a few of the specimens photographically.
7. Nitrogen produced very sound specimens.
8. An excessive volume of blowholes was found with hydrogen.
9. The addition of iron oxide in the presence of carbon monoxide increases the blowholes. Owing to the reaction,



it is to be expected that this addition would give results similar to those obtained in an atmosphere of carbon dioxide; this is found to be the case, and is also confirmed by the effect of the addition of oxide in the presence of coal-gas.

10. In the carbon dioxide experiments the metal round the blowholes was found to contain less carbon than the remainder, presumably due to decarburisation by the carbon dioxide during cooling, which is in agreement with the views of many previous investigators. On the other hand, with coal-gas the metal adjacent to the blowholes was carburised, probably by the hydro-carbons.

CONCLUSIONS.

1. The presence of carbon dioxide, whether by direct introduction or as a product of the interaction of carbon monoxide and iron oxide, definitely gives rise to blowholes.

2. In the presence of carbon monoxide the metal is very much more sound. The fact that the specimens in the carbon monoxide series were not completely free from blowholes may be ascribed to two causes—

- (a) Very small amounts of carbon dioxide being formed during the passage of the carbon monoxide into the furnace, and also by interaction with the small quantity of oxide in the metal ; this is possibly the main cause.
- (b) The rate of cooling adopted bringing about a state of supersaturation of the liquid metal with the gas before actual solidification.

The few blowholes which are formed do not, therefore, detract from the comparisons made between the effects of the two gases.

3. Mere solubility of those gases likely to be present in molten iron does not in itself cause blowholes, ingots extremely free from blowholes being produced in the nitrogen melts. It might be suggested that the nitrogen did not go into the metal at all, but the fact that nitrogen is soluble in molten steel has been shown by many workers from its presence in blowhole gas, found by many workers.

4. Hydrogen plays no part in McCance's arguments. In these experiments, where the metal was subjected to an atmosphere of pure hydrogen, very considerable blowhole formation resulted. A possible explanation is that the rate of cooling was too great to allow the very large volume of gas absorbed at the high temperature to escape during the liquid phase of cooling. Sieverts ⁽⁶⁾ has shown that the solubility of hydrogen decreases rapidly with the fall of temperature, and very suddenly at the melting point. On the other hand, it may receive an explanation somewhat similar to that given by McCance for carbon dioxide. The hydrogen may react with oxide in the metal, forming steam, which either directly, or indirectly by reaction with the carbon in the steel forming carbon dioxide, would form blowholes. The carburisation of the metal in this experiment is probably the result of the

direct synthesis of hydrocarbons from hydrogen and the carbon of the tube.

5. It is seen that the temperature is an extremely important factor. This again is possibly due to the time effect in cooling already referred to, and it is just possible that, if the rate of cooling were very slow, the maximum temperature would be unimportant.

The general conclusion is reached that McCance's hypothesis is definitely confirmed by these experiments, and that whilst other factors have been shown to play a part in the formation of blow-holes under these experimental conditions, these factors, with the exception of temperature, would be relatively unimportant in steel-melting practice.

APPENDIX.

Small test-pieces were cut from a number of specimens for tensile strength determinations. Owing to the difficulty encoun-

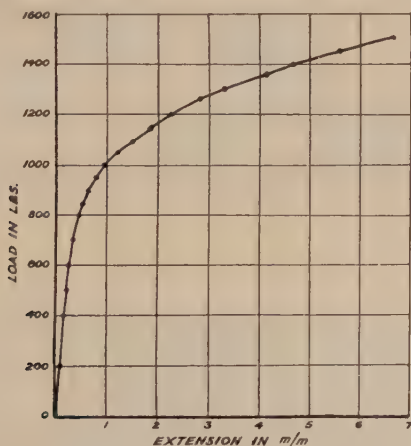


FIG. 5.—Load/Extension Curve.

tered with the blowholes a complete series of comparative results could not be obtained. The results of a few sound test-pieces are given in the table on p. 224.

The load-extension curves are interesting in that they show no yield point. A typical curve, that obtained from specimen No. 5, is shown in Fig. 5. Arrowsmith⁽⁷⁾ has shown that, in Armco

TABLE II.

Experiment Number.	Gas.	Maximum Stress. Tons per Sq. In.	Elastic Limit. Tons per Sq. In.	Reduction of Area per Cent.	Elongation per Cent.
20	CO ₂	22.06	5.932	53.75	41.82
12	CO ₂	20.68	8.489	59.51	39.43
23	CO ₂	20.55	10.09	51.93	32.88
13	CO	20.38	10.21	57.38	45.28
5	N ₂	19.71	7.787	56.62	32.29
7	Coal-gas	21.59	8.551	57.11	35.88

iron, as the grain-size increases the yield point diminishes, and finally disappears.

This work on the influence of gases is being continued, and further results will appear in due course.

The authors wish to take this opportunity of thanking Professor F. C. Thompson, of the Metallurgical Department of the University of Manchester, for suggesting the undertaking of this investigation, which was carried out in the Electrochemical Department of the University.

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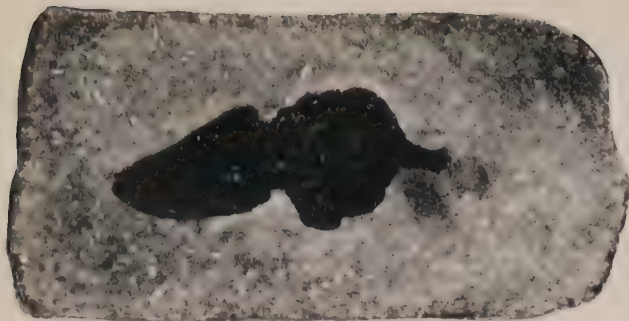


FIG. 8.—Experiment 23 CO_2 .
2054° C. $\times 13$.



FIG. 7.—Experiment 12. CO_2 .
1737° C. $\times 13$.

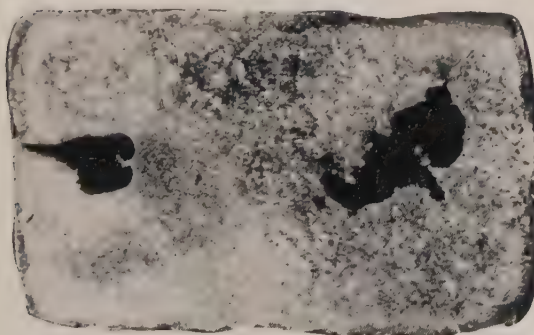


FIG. 6.—Experiment 10. CO_2 .
1657° C. $\times 13$.



FIG. 12.—Experiment 9. $\text{CO} + \text{Fe}_2\text{O}_3$.
1694° C. $\times 1\frac{1}{3}$.

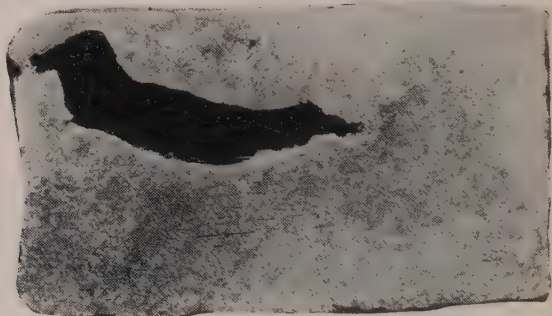


FIG. 11.—Experiment 33. CO .
2054° C. $\times 1\frac{1}{3}$.

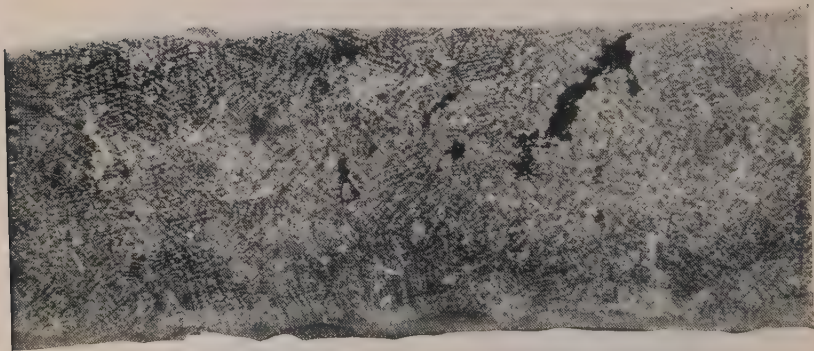


FIG. 10.—Experiment 2. CO .
1694° C. $\times 1\frac{1}{3}$.

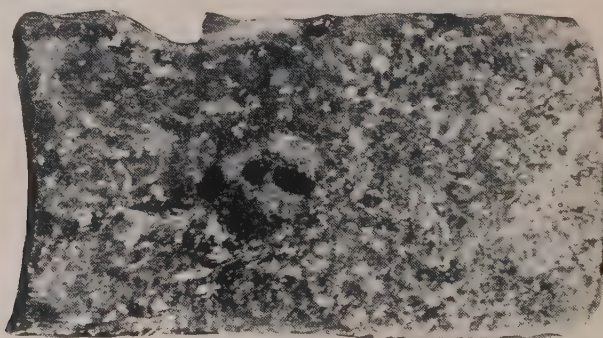


FIG. 9.—Experiment 29. CO .
1666° C. $\times 1\frac{1}{3}$.

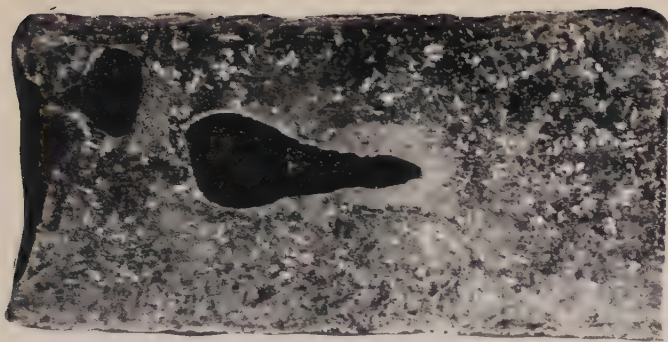


FIG. 16.—Experiment 7. Coal gas + Fe_2O_3 . 1694°C . $\times 13$.

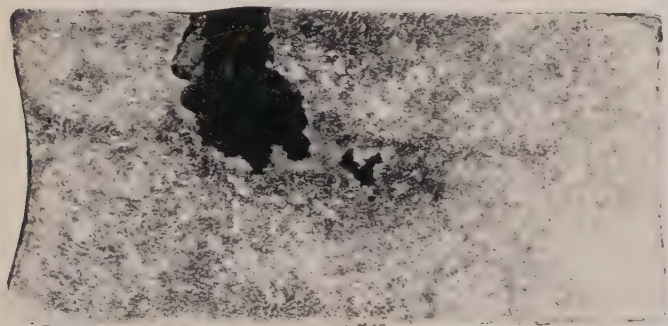


FIG. 15.—Experiment 6. Coal gas. 1700°C . $\times 13$.

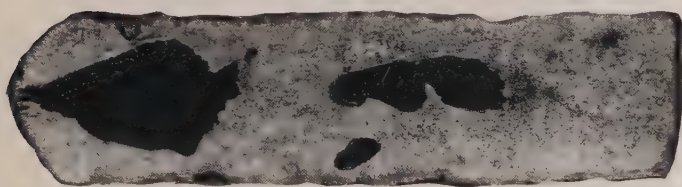


FIG. 14.—Experiment 8. H_2 . 1694°C . $\times 13$.

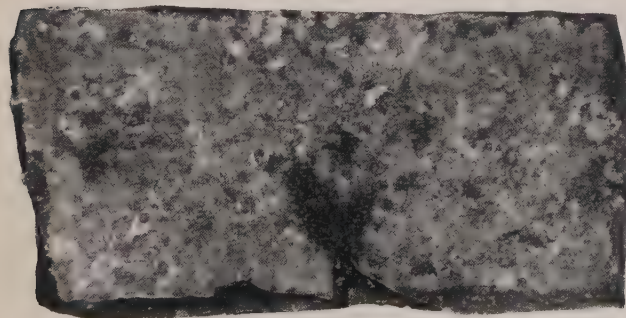


FIG. 13.—Experiment 5. N_2 . 1700°C . $\times 13$.

DISCUSSION.

Professor THOMAS TURNER (Member of Council, Birmingham University), in opening the discussion, said that the authors had given a very interesting paper. The question of the solidity of an ingot, whether of iron or of any other metal, was obviously one of the very greatest importance. Solidity would depend upon two chief factors. One was the rate and manner of the contraction of the metal, determining whether it could freely feed itself as solidification took place. The other was the evolution of the gas which was given off during solidification. That would depend upon the solubility of the gas, and the temperature coefficient of that solubility, which determined whether the solubility of the gas changed very rapidly with change of temperature. Bamford and Ballard had carried out a number of experiments on brass at Birmingham in an endeavour to ascertain the effect of gaseous atmospheres upon the solidarity of the casting, and it was found that many gases, such as hydrogen, carbon monoxide, and sulphur dioxide, might form the atmosphere of the crucible in which the metal was being melted, and that quite satisfactory castings could still be obtained. It was rather a question of the temperature and method of casting; of allowing the superheated fluid metal to cool slightly so as to give off the gas, and then pouring steadily so as not to splash or to entangle any further gases. To some extent the same thing would no doubt be true in reference to the iron with which the authors had experimented, as was indicated in their paper. He always felt that the best illustration in regard to the casting of metals could be obtained from the case of ice and water. When ice was allowed to form very slowly, "black ice," corresponding with a solid metal, was obtained. If the water was cooled very quickly, so that the gas was not allowed to escape, but remained entangled in the water in the form of bubbles, an opaque ice corresponding to metal treated in a similar manner was obtained. Obviously, therefore, what they had to aim at was to give the metal time to get rid of any excess of gas before it was poured, and not to have too high or too low a temperature during pouring. To a certain extent those things had been indicated by the authors in their paper.

The special point of interest in the paper was in relation to the effect of carbon dioxide. Carbon dioxide appeared to be less soluble in steel than hydrogen, and to be more injurious. So far as he understood, that was the chief point which the authors had made, and he thought the members were indebted to them for their contribution to the subject.

Dr. A. McCANCE (Uddingston) said that the subject of the paper was of particular interest to him, and he thought the authors were to be congratulated for the skill with which they had tackled one of the most

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difficult subjects. It was a subject of the highest practical importance, bristling with difficulties, and it no doubt required a considerable amount of courage to start out on any scheme of experimental research. He had himself several times contemplated the idea, but he thought he had always too readily perhaps found refuge in the proverb of "Never doing to-day what could be put off till to-morrow." With regard to the underlying idea that carbon dioxide was less soluble than carbon monoxide, he thought that was substantially true, but in the experiments which the authors had put forward there were so many interfering factors that he thought they would agree with him in stating that the conclusions which they had come to were not quite definitely proved, because, when they were passing carbon dioxide into the apparatus in the presence of heated carbon and in the presence of molten iron, there was bound to be chemical action taking place which would alter the composition of the gases. Unless the composition of the gases were analysed and determined, it would be difficult to say whether when carbon dioxide was added to the furnace actually pure carbon dioxide was being retained in contact with the molten steel. In fact, he thought that it would be definitely stated that the pure gas was not in contact with the steel, but that some mixture was really the determining factor.

With regard to distinguishing between shrinkage cavities and blowholes, unless the ingots were cooling from the bottom and the top kept liquid, there would be a shrinkage cavity formed, which would rather interfere with the figures. He thought, however, that both the authors would agree that the work on which they were engaged, though very important, was only preliminary, although he would be very glad indeed if they would continue it along similar lines, while trying to eliminate some of those interesting factors which he had just mentioned. It was, undoubtedly, a question of the greatest practical significance, and all steel-makers would welcome very considerably a definite pronouncement on the question of the solubility of gases in steel, because it was an extremely important matter to them in so many ways.

Dr. T. SWINDEN (Sheffield) agreed with Dr. McCance as to the importance of the authors' work to steel-makers. He doubted, however, whether the general conclusions they arrived at were warranted. In effect, the conclusions really meant that blowholes in steel-making practice were due entirely to carbon dioxide. He did not think that the data presented were sufficient to substantiate that view. The title of the paper would more nearly represent the subject-matter if it read "with special reference to the formation of cavities" rather than "blowholes," because obviously the cavities shown in some of the illustrations were shrinkage cavities and not blowholes in the ordinary sense of the word. The serious carburisation of some of the samples, and the initial temperature should be taken into account as regards shrinkage cavities.

The further point that Dr. McCance had referred to, with reference to keeping the top of the ingot open, was very important from the

practical point of view, and he was led to ask whether the exact pressure of the gas was controlled in each case. That would have a bearing on the setting of the surface during cooling and the speed with which the gas was passed through. In fact, a study of the monumental work of Brinell on the subject of blowholes would be well worth while. He would also suggest that conclusions 3 and 4 were rather contradictory. In paragraph 3 the mere solubility of the gases likely to be present in molten iron did not in itself, it was stated, cause blowholes, as evidenced from the nitrogen experiments, but the first possible suggestion in regard to hydrogen was that the blowholes were formed because the hydrogen had dissolved to a very large extent, and had not had time to come out. He took it that the blowholes in the ordinary sense of the word were formed during the period of solidification of an ingot due to gases being evolved and trapped in viscous metal, and he thought there was considerable evidence in published works to show that hydrogen could not be ignored in that direction. He would refer the authors to the work of Baraduc Muller (*Carnegie Memoirs*, 1914), where he (Muller) analysed the gases given off by steel in cooling, from the liquid to the cold state. He would quote one or two figures with regard to that matter. In the liquid state the gases contained carbon monoxide 43 per cent. and hydrogen 38 per cent. During cooling down, just before solidification, the carbon monoxide was 40·8 per cent. and the hydrogen 28·4 per cent., but immediately the surface of the ingot began to set the carbon monoxide fell to 24·8 per cent. and the hydrogen rose to 60 per cent., and an analysis taken subsequently showed hydrogen as high as 68 per cent. and carbon monoxide 15 per cent. The total volume of gas was greatest during solidification. That, of course, indicated that there was a tremendous evolution of hydrogen at the time of solidification (as subsequently confirmed by Sieverts), and if blowholes were formed as he thought, it was very unwise to put forward such a definite conclusion that carbon dioxide was the only cause to be seriously considered in reference to blowholes in steel.

His (Dr. Swinden's) own views were more fully explained in a paper read before the Staffordshire Iron and Steel Institute, 1922.

CORRESPONDENCE.

MR. FRANK ADCOCK, M.B.E., B.Sc. (Teddington), wrote that the authors had produced a number of small ingots containing cavities, and in the discussion speakers had pointed out that those might have been produced either by shrinkage of the metal or by evolution of gas on solidification.

A considerable number of ingots of electrolytic iron and iron alloys had been made recently at the National Physical Laboratory in small high-frequency induction furnaces which were arranged for vacuum

melting. Usually the metal was maintained in the liquid state until the pressure of gas within the furnace was reduced to the equivalent of 1 millimetre of mercury, and then the melt was allowed to solidify. The ingots were of similar dimensions to those made by the authors, and when examined were found to contain quite large cavities (comparable with those shown in Fig. 11 of the authors' paper).

Although probably initiated by small bubbles of gas in the upper parts of the ingots, the presence of numerous projecting dendrites suggested that shrinkage of the metal was chiefly responsible for the hollowness of the ingots.

The authors did not appear to have made ingots of vacuum-treated metal in order to ascertain the size of the cavities produced when the gas in the metal was reduced to a minimum.

Some check was essential if the figures given for the percentage volume of the blowholes in Table I. were to be regarded as anything more than rough approximations. The proper control of the atmosphere in a furnace such as that used by the authors was practically impossible, and the melts could hardly remain unaffected by the large quantities of gas evolved from the incandescent carbon. Should a more suitable type of furnace not have been available, matters could have been improved by placing the melts in a refractory muffle or tube, in order to restrict the action of the furnace gases.

The authors mentioned that the investigation was to be continued. While they were to be congratulated on their preliminary survey, it seemed that refinement of experimental methods would greatly enhance the value of their further work on the subject.

Mr. T. P. COLCLOUGH (Rotherham) wrote that the authors were to be complimented on the excellent way in which they had overcome the practical difficulties found in conducting experiments at such high temperatures. Unfortunately, they did not appear to have given an equal amount of consideration to theoretical aspects of the problem.

It was now well established that neither carbon monoxide nor dioxide was stable at the temperatures of the experiments, and any conclusions to be drawn from the authors' data must be examined in the light of those facts.

(1) Carbon dioxide at such temperatures showed an appreciable amount of dissociation, $2\text{CO}_2 \rightleftharpoons 2\text{CO} + \text{O}_2$, and the higher the temperature the greater the degree of dissociation. Also, since there was a constant stream of gas through the apparatus, there would be a tendency to maintain that dissociation, at a stage beyond the equilibrium point.

The oxygen thus formed would combine rapidly with the iron to form an oxide Fe_xO_y , and the higher the temperature, the more oxidised would be the metal.

(2) Similarly, the carbon monoxide used, or formed, would dissociate, yielding carbon and the dioxide $2\text{CO} \rightleftharpoons \text{C} + \text{CO}_2$. That action pro-

ceeded more rapidly in the presence of iron. From that it followed that the metal would become carburised during the experiments.

The facts observed by the authors were, therefore, not simply those due to the solution of more or less of CO_2 or CO , but were also indications as to how far the above actions had proceeded, for when the metal was cooling the iron oxide and carbide formed would react, yielding gases which would cause blowholes. The higher the temperature the greater would be the degree of oxidation of the metal, and the greater the tendency to form blowholes.

That those reactions had been proceeding was demonstrated by the authors on p. 221, where they stated: "In the carbon dioxide experiments the metal round the blowholes was found to contain less carbon than the remainder." Did not that fact point to the conclusion that the blowhole was the result of the C/FeO reaction? Note 9, p. 221, was also capable of a similar explanation: "The addition of iron oxide in the presence of carbon monoxide increases the blowholes."

As indicated above, the carbon monoxide carburised the metal, and that carbide reacted with the oxide to give the blowholes. In view of those considerations, it was difficult to see how the experiments supported, or otherwise, the hypotheses of McCance regarding the solubilities of the two oxides of carbon in iron. The phenomena observed by the authors might have been due to the causes which they advanced, but they might have been equally well explained by other hypotheses. Further, and more discriminating, work was required before a definite conclusion could be arrived at.

Mr. LOBLEY, replying to the verbal discussion, said that the statement had been made that the cavities found were not true blowholes, but were due to shrinkage after the top had solidified. That, however, did not appear probable in view of the fact that the whole crucible was cooled down as uniformly as possible, the gas stream not being vigorous during the cooling down, so that there would be little or no influence which would cause the top to cool more rapidly than the bottom.

The Author in a further written reply, pointed out, that insufficient attention had been directed to the theoretical aspects, and that the presence of carbon made the atmospheric conditions in the furnace uncertain.

The first point was important and had already been dealt with to some extent in the verbal reply; it might also be observed that the conditions of cooling were identical in each experiment, so that if the cavities were entirely due to shrinkage they would presumably have been found equally in each experiment, whereas such was not the case. To confirm that, special provision had been made in experiments now in progress for cooling the bottom faster than the top of the crucible.

Full consideration was given to the theoretical aspects by the authors, but it was not thought necessary to deal with them at length in the paper. Mr. Colclough referred to the instability of carbon monoxide and carbon dioxide under the conditions of the experiments,

and detailed some of the equilibrium relations which might be expected. Those relations appeared obvious, and had been taken for granted. As Mr. Colclough observed, carbon dioxide in the presence of iron was in equilibrium with carbon monoxide and iron oxides, but how far the reaction proceeded one way or the other was immaterial to the point at issue; the only point of interest was that it would be expected that carbon monoxide and oxidised iron would give the same result as carbon dioxide, which was precisely what was found. Although expected, carburisation of the metal in the carbon monoxide experiments was not found; yet, on the other hand, decarburisation in the neighbourhood of the blowholes was found in the case of carbon dioxide. Whether carbon dioxide entered the metal as such at high temperatures, or brought about oxidation of the metal, could make little difference, since in the latter case, on cooling, carbon dioxide would re-form in sufficient quantities to produce the same effect.

Although the presence of carbon dioxide also involved the presence of carbon monoxide and *vice versa*, in the one case oxidation occurred in bringing about the equilibrium conditions, in the other the reverse. It might also be noted that the gases impinged on the metal before coming in contact with solid carbon; there would thus be little opportunity for any reaction between the gas and carbon until after leaving the vicinity of the metal.

It appeared to be necessary to emphasise that definite differences were found with the various gases used, and that fact in itself seemed largely to discount much of the criticism. Moreover, the authors could not agree that the above speculations affected the results obtained, the chief of which was that carbon dioxide produced excessive blowhole formation whilst carbon monoxide did not, and so far as they were aware that had not been experimentally demonstrated before.

With regard to Dr. Swinden's suggestion as to the hydrogen and nitrogen conclusions, the very great change in the solubility of the hydrogen at the melting point would account for the difference in behaviour of the two gases, so that those conclusions were not really contradictory. In the case of hydrogen, the authors had suggested that under their conditions it might not be able to free itself from the cooling metal sufficiently rapidly owing to the large quantity which had been taken up. That brought in the question of the rate of cooling, which it would be possible to control over a large range in their future work. The work, however, was only preliminary, and they were continuing it with a modified apparatus in order to obtain more general information.

Iron and Steel Institute.

TEMPER-BRITTLENESS OF STEEL; SUSCEPTIBILITY TO TEMPER-BRITTLENESS IN RELATION TO CHEMICAL COMPOSITION.¹

By R. H. GREAVES AND J. A. JONES
(RESEARCH DEPARTMENT, WOOLWICH).

In previous papers the authors have described some of the phenomena of temper-brittleness occurring in nickel-chromium and other steels.² Although no explanation of temper-brittleness has yet been arrived at, it may be of interest to record further work done on the subject, especially as some important practical conclusions regarding composition and correct heat treatment may be drawn from the results. These results relate to: (1) susceptibility to temper-brittleness, and (2) the behaviour of the steel after treatment in the embrittling range of temperature. Some previous conclusions on these two aspects of the subject are summarised below, and are referred to in subsequent sections.

SUSCEPTIBILITY TO TEMPER-BRITTLENESS.

The susceptibility of a steel to temper-brittleness is measured by the ratio of the impact figure of a sample rapidly cooled after tempering to that of a sample slowly cooled, the previous history being the same in each case. The following procedure was adopted as the standard test for susceptibility. Two similar samples of the steel were taken, oil-hardened from 900° C. and tempered for two hours at 650° C. One sample was cooled in water after tempering, and the other cooled slowly, the rate of cooling between 600° and 400° C. being uniform and 0·3° C. per minute. The ratio of the impact figures of these samples was taken as expressing susceptibility under standard conditions. If 650° C. too nearly approached the critical range of the steel, a slightly lower tempering temperature was employed.

¹ Communication from the Research Department, Woolwich.

² *Journal of the Iron and Steel Institute*, 1919, No. II. p. 329; 1920, No. II. p. 171.

The numerical value of the susceptibility ratio of any given steel depends on the conditions of hardening and tempering, and on the rate of cooling from the tempering temperature. Thus a steel which might be classed as not susceptible, when a rate of cooling of 3°C. per minute is employed, may show a reduced impact figure after cooling at a rate of 0.3° per minute. After hardening from a high temperature a lower impact figure is in general produced by the same rate of cooling after tempering, although it appears that a sufficiently slow rate of cooling may produce the same brittle figure from the steel hardened from the lower temperature.¹

If two samples of a steel which is susceptible to temper-brittleness be hardened, reheated to a temperature approaching Acl and then retempered at 600°C. , one being quickly and the other slowly cooled, the susceptibility ratio based on these figures is reduced as the critical range is approached in the first reheating.²

Some preliminary experiments were described in which differences in susceptibility were produced by preliminary heating in hydrogen and in carbon dioxide, thus, as was at that time thought, indicating the possibility of influencing susceptibility to temper-brittleness by chemical action of these gases on the steel.³ The experimental results have been confirmed, but the effect may be explained purely on the difference in grain-size which is induced by treatment in the gases mentioned under otherwise identical conditions; it becomes, in fact, analogous to that of varying the hardening temperature.

The usual small differences in composition occurring in high-grade steel of the type containing 0.25 per cent. of carbon, 3.5 per cent. of nickel, and 0.6 per cent. of chromium, were found to be secondary in importance to the possible influence of the method of manufacture. This influence was held to be not definitive but indirect, in the sense that conditions producing susceptibility to temper-brittleness were more frequently present in acid open-hearth steels than in electric furnace steels, while crucible steels were in general less susceptible than either. Moreover, it was held that this effect was certainly not merely due to phos-

¹ *Journal of the Iron and Steel Institute*, 1920, No. II. p. 190.

² *Loc. cit.* (for another example see R. H. Greaves, "German Gun Steels," *Research Department, Woolwich, R.D. Report*, No. 57).

³ *Loc. cit.*, p. 200.

phorus content.¹ Subsequently, it was found that by considering variations in phosphorus and manganese jointly² it was possible to make a much closer estimate of the susceptibility of steels of the same type, though the indications so afforded were uncertain as regards steels with phosphorus under 0.035 per cent. and manganese under 0.4 per cent., showing the existence of some additional factor not taken into consideration. With wider limits of phosphorus and manganese than should normally be met with, electric furnace steels and crucible steels showing extreme susceptibility may readily be produced. Even within the normal limits of manganese and phosphorus content, electric furnace steels showing great susceptibility appear to be more common when the chromium content is high. On the other hand, it seems that by the addition of molybdenum susceptibility to temper-brittleness is invariably reduced. One of the merits of the nickel-chromium-molybdenum steels, for the introduction of which Messrs. Sir W. G. Armstrong, Whitworth & Co. are mainly responsible, is that they are non-susceptible to temper-brittleness. No rate of slow cooling from the tempering temperature likely to be met with in practice has any effect in reducing the impact figure. No sample of acid open-hearth nickel-chromium-molybdenum steel examined by the authors has had its average impact figure reduced more than 2 ft.-lbs. by slow cooling after tempering.³ Even when a rate of cooling of only 1° C. in sixteen minutes has been employed over the whole range, 600° to 450° C., the reduction in impact figure has not exceeded 2 ft.-lbs.

THE EMBRITTLING RANGE OF TEMPERATURE.

The transformation of nickel-chromium steels from the tough to the brittle condition in the vicinity of 550° C. occurs, not at a definite temperature, but over a range of temperatures within which there appears to be equilibrium between the condition producing toughness and the condition producing brittleness. If

¹ *Journal of the Iron and Steel Institute*, 1920, No. II. (authors' reply to discussion), p. 222.

² As suggested by L. Grenet, *Journal of the Iron and Steel Institute*, 1919, No. II. p. 392.

³ J. A. Jones, "The Properties of some Nickel-Chromium Steels," *Research Department, Woolwich, R.D. Report*, No. 55, p. 43.

two samples of the same hardened and tempered steel, one initially in the tough and the other in the brittle condition, be

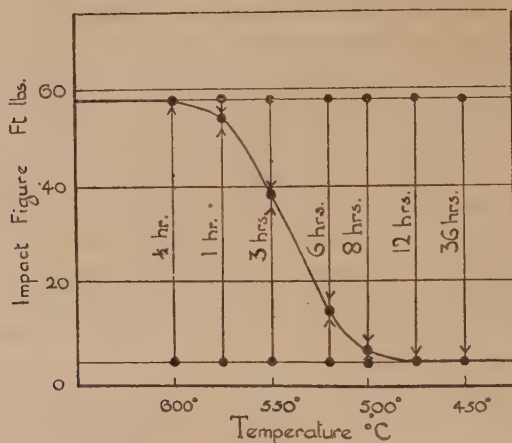


FIG. 1.—Embrittling Range, and Time taken to attain the Equilibrium Impact Figure, in the acid open-hearth nickel-chromium steel of the following composition :

C.	Si.	Mn.	S.	P.	Ni.	Cr.
0.26	0.07	0.66	0.020	0.026	3.53	0.84

oil-hardened from 1000° C. and tempered at 650° C.

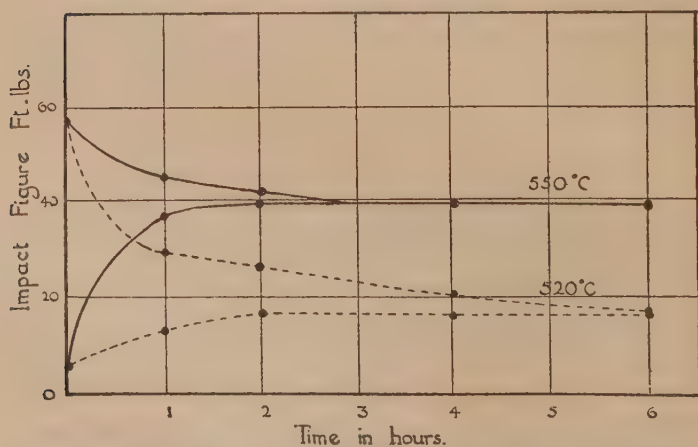


FIG. 2.—Rate of Change of Impact Figure of Tough and Brittle Specimens Heated at Different Temperatures within the Embrittling Range and Quenched in Water.

heated to any temperature within the range for a sufficient time and then quenched in water, they attain to the same impact figure. The behaviour of a typical susceptible steel is illustrated in Figs. 1 and 2.¹

The difference in the rate of attaining the equilibrium impact figure at a given temperature is not very great for different steels, but the rate diminishes very rapidly with fall of temperature.

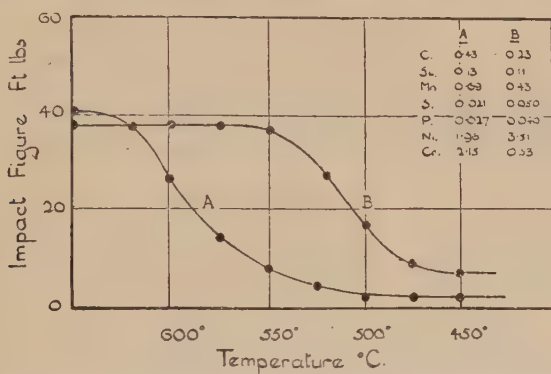


FIG. 3.—Highest and Lowest Embrittling Ranges observed in Commercial Steels.

Hence a steel with a high embrittling range has a far better opportunity of continuing in equilibrium during any process of slow cooling, and so of attaining a low impact figure. Differences of 30° or 40° C. in the position of the upper limit of the range were observed in steels of the same type, the higher ranges being associated with greater susceptibility to temper-brittleness. The highest and lowest ranges observed in the commercial steels examined are shown in Fig. 3.

THE INFLUENCE OF CHEMICAL COMPOSITION ON SUSCEPTIBILITY.

Material Used and Experimental Details.

All the steels used in the work now described were (except where otherwise stated) crucible steels, and each series was made

¹ *Journal of the Iron and Steel Institute*, 1920, No. II. p. 177 (Steel D).

from the same raw materials under identical conditions. Ingots weighing about 100 lbs. were rolled into bar $1\frac{1}{2}$ inch by $\frac{3}{4}$ inch in section, from which specimens were cut for heat treatment in the laboratory. The conditions under which heat treatment and mechanical tests were carried out were identical with those

TABLE I.—*Chemical Analysis—Crucible Steels.*

No. of Steel.	Mark.	C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.	V.
1	BMC	0.37	0.12	0.25	0.042	0.023	0.07	0.05	...	...
2	CDN	0.39	0.11	1.12	0.035	0.025	nil	nil	...	...
3	CDO	0.36	0.09	2.24	0.027	0.025	nil	nil	...	...
4	CDP	0.39	0.24	2.86	0.031	0.025	nil	0.04	...	...
5	DDJ	0.64	0.27	1.21	0.015	0.031	nil	0.03	...	...
6	BME	0.38	0.15	0.22	0.052	0.026	0.07	1.43	...	...
7	DDD	0.40	0.16	0.60	0.017	0.025	nil	1.72	...	...
8	DDH	0.50	0.18	0.91	0.018	0.026	nil	1.73	...	...
9	DCZ	0.42	0.15	0.17	0.036	0.021	3.09	0.01	...	...
10	DDA	0.39	0.08	0.60	0.016	0.026	2.98	nil	...	...
11	DDB	0.34	0.10	0.83	0.018	0.027	3.00	nil	...	...
12	DDC	0.43	0.15	1.60	0.017	0.028	2.96	nil	...	...
13	OL	0.39	0.07	0.32	0.042	0.020	3.76	nil	...	...
14	OM	0.38	0.05	0.43	0.038	0.019	3.97	nil	...	...
15	ON	0.41	0.05	0.56	0.038	0.018	3.94	nil	...	...
16	OP	0.41	0.08	0.80	0.038	0.018	3.95	nil	...	...
17	OQ	0.41	0.06	0.94	0.036	0.018	4.02	nil	...	...
18	DDF	0.32	0.06	0.12	0.032	0.020	3.36	0.63	...	...
19	DDG	0.33	0.06	0.27	0.020	0.023	3.38	0.63	...	...
20	DDE	0.31	0.09	0.65	0.029	0.025	3.65	0.63	...	...
21	DDK	0.33	0.09	0.26	0.011	0.023	2.65	1.74	...	...
22	DDL	0.35	0.11	0.45	0.011	0.023	2.51	1.73	...	...
23	DDM	0.32	0.11	0.60	0.016	0.026	2.58	1.65	...	...
24	DDO	0.35	0.11	0.91	0.014	0.027	2.55	1.59	...	...
25	DQJ	0.31	0.06	0.17	0.024	0.023	3.67	nil	...	...
26	DQK	0.36	0.09	0.22	0.031	0.084	3.60	0.01	...	...
27	DQL	0.33	0.08	0.24	0.033	0.144	3.62	0.01	...	...
28	DQQ	0.28	0.04	0.23	0.025	0.026	3.61	0.71	...	...
29	DQR	0.30	0.08	0.24	0.024	0.090	3.58	0.70	...	...
30	DQS	0.30	0.08	0.22	0.028	0.136	3.62	0.70	...	...
31	EHS	0.23	0.13	0.53	0.020	0.079	3.69	0.84	...	...
32	CBH	0.42	1.34	0.49	0.038	0.022	3.32	nil	...	...
33	CBG	0.59	1.85	0.65	0.043	0.021	nil	0.02	...	...

TABLE I.—*Chemical Analysis (continued).*

No. of Steel.	Mark.	C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.	V.
34	DNW	0.34	0.09	0.21	0.034	0.022	2.66	nil	...	0.38
35	DOA	0.34	0.09	0.17	0.041	0.024	2.63	0.01	...	0.61
36	BMD	0.37	0.13	0.22	0.039	0.024	0.07	0.75	...	nil
37	DOM	0.30	0.07	0.19	0.032	0.021	nil	0.65	...	0.39
38	DON	0.36	0.12	0.19	0.034	0.022	nil	0.63	...	0.63
39	DOO	0.36	0.12	0.21	0.037	0.022	nil	1.20	...	0.38
40	DOP	0.34	0.11	0.21	0.033	0.022	nil	1.20	...	0.68
41	DNY	0.34	0.10	0.18	0.038	0.025	2.62	0.68	...	0.36
42	DNZ	0.36	0.11	0.22	0.041	0.025	2.57	0.64	...	0.68
43	DNX	0.35	0.11	0.19	0.040	0.023	2.61	1.18	...	nil
44	DOH	0.31	0.11	0.21	0.033	0.020	2.60	1.19	...	0.34
45	DOJ	0.31	0.12	0.20	0.041	0.021	2.67	1.18	...	0.61
46	DOK	0.41	0.12	0.22	0.040	0.022	2.63	1.23	...	0.37
47	DOL	0.46	0.15	0.20	0.047	0.023	2.60	1.21	...	0.65
48	DOD	0.34	0.11	0.19	0.043	0.020	5.15	0.61	...	0.36
49	DOE	0.30	0.11	0.20	0.040	0.024	5.03	0.63	...	0.61
50	DKD	0.36	0.08	0.21	0.027	0.024	1.74	1.08	nil	...
51	DKE	0.34	0.09	0.19	0.027	0.024	1.72	1.08	0.61	...
52	DKF	0.37	0.08	0.19	0.025	0.025	1.69	1.08	1.06	...
53	DKG	0.40	0.12	0.22	0.035	0.025	2.73	0.56	nil	...
54	EMD	0.27	0.09	0.31	0.047	0.022	2.53	0.66	0.37	...
55	DKH	0.33	0.07	0.17	0.035	0.025	2.70	0.58	0.57	...
56	DKJ	0.35	0.07	0.23	0.032	0.025	2.67	0.59	1.01	...
57	DKK	0.31	0.09	0.24	0.026	0.024	2.80	1.15	nil	...
58	DKL	0.33	0.12	0.25	0.032	0.023	2.81	1.18	0.58	...
59	DWW	0.30	0.15	2.30	0.028	0.025	nil	nil	0.52	...
60	EHM	0.24	0.11	0.16	0.033	0.070	3.48	0.77	0.38	...
61	EHO	0.29	0.12	0.18	0.033	0.074	3.58	0.80	0.59	...
62	EHP	0.35	0.14	0.86	0.027	0.024	3.68	0.60	0.34	...
63	EHR	0.28	0.15	0.72	0.026	0.034	3.73	0.82	0.65	...
64	EMP	0.25	0.07	0.66	0.033	0.020	2.55	0.66	0.63	...

described in the previous paper. No reference is here made to the conditions of treatment which yield the best combination of properties for each steel; and the steels are not compared on the basis of their general mechanical properties, but solely on their susceptibility to temper-brittleness.

The chemical analysis of the steels is given in Table I. The following limits generally apply throughout, except in steels in which the element in question was purposely introduced in larger quantities : Manganese, 0.25 per cent. ; silicon, 0.15 per cent. : sulphur, 0.04 per cent. ; and phosphorus, 0.03 per cent.

The Effect of Manganese.

Carbon steels with low manganese and phosphorus are only very slightly (if at all) susceptible to temper-brittleness, but increase in manganese content leads to increased susceptibility (Table II.). The susceptibility of steels with over 2 per cent. of manganese is very marked, but good impact figures can be obtained by suitable treatment.¹

TABLE II.—*Susceptibility of Carbon Steels with High Manganese Content.*

Izod impact figures after different rates of cooling from the tempering temperature.

No. of Steel.	Carbon per Cent.	Manganese per Cent.	Oil-hardened from 900° C. Tempered at 650° for 2 Hours and Cooled at the following Rates.					Susceptibility Ratio.
			In Water.	In Air.	2.5° C. per Minute.	1° C. per Minute.	0.3° C. per Minute.	
1	0.37	0.25	32	...	...	...	29	1.1
2	0.39	1.12	11	11	10	8	5	2.2
3	0.36	2.24	74	63	10	6	4	18.5
4	0.39	2.86	57	36	8	3	2	28.5
5	0.64	1.21	52	...	...	...	23	2.3

The position of the range of temperature within which the steels develop temper-brittleness, and the times required for tough and brittle material to arrive at the same condition as regards impact figure, when heated within the range, have been determined for steels 3 and 4. A supply of tough and brittle material having been obtained from both steels, specimens were reheated at temperatures between 475° C. and 620° C. for various times. At the end of the required time the specimens were withdrawn, cooled in water, and tested : the results are given in Tables III. and IV., and are shown in Fig. 4. The position of the ranges

¹ J. A. Jones, "The Properties of Medium Carbon Steel with High Manganese Content," *Research Department, Woolwich, R.D. Report, No. 61, p. 9.*

(600° to 475° C. and 610° to 475° C. for the steels with 2.24 and 2.86 per cent. of manganese respectively) was within the limits observed for commercial nickel-chromium steels.

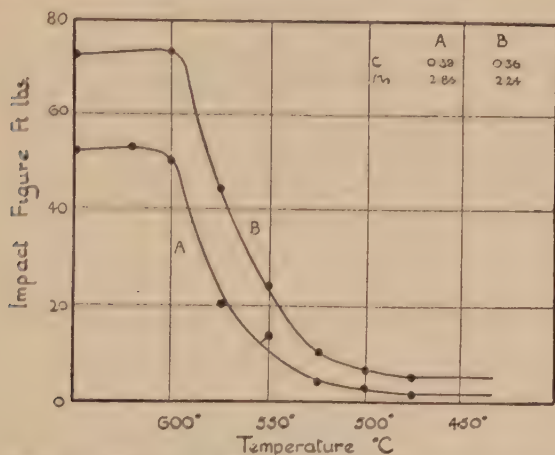


FIG. 4.—Embrittling Range of Carbon Steels with High Manganese Content.

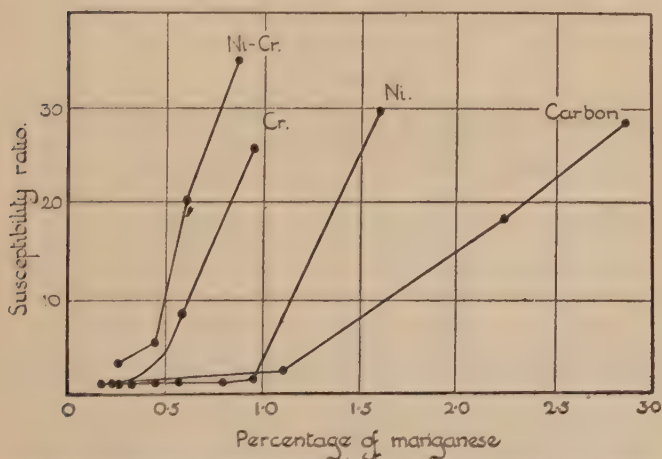


FIG. 5.—Relation between Susceptibility and Manganese Content.

The results of varying the manganese content in chromium, nickel, and nickel-chromium steels are shown in Table V. After a certain percentage is exceeded an increase in manganese content has a marked influence on susceptibility. This influence is

TABLE V.—*Susceptibility of Chromium, Nickel, and Nickel-Chromium Steels with Differing Manganese Content.*
Izod impact figures (ft.-lbs.).

Type of Steel.	No. of Steel.	Man- ganese per Cent.	Oil-hardened from 900° C.			Oil-hardened from 1000° C.		
			Tempered at 650° C. ¹ for 2 Hours and Cooled.					
			In Water.	0-3° C. per Minute.	Ratio.	In Water.	0-3° C. per Minute.	Ratio.
C. 0.4 per cent.	6	0.22	66	62	1.1	59	41	1.4
Cr. 1.6 ,,	7	0.60	59	7	8.4	59	7	8.4
	8	0.91	51	2	25.5	51	2	25.5
C. 0.4 per cent.	9	0.17	68	67	1.0	71	70	1.0
Ni. 3.0 ,,	10	0.60	84	74	1.1	86	77	1.1
	11	0.83	74	53	1.4	72	50	1.4
	12	1.60	59	2	29.5	59	2	29.5
C. 0.4 per cent.	13	0.32	60	58	1.0	58	55	1.0
Ni. 4.0 ,,	14	0.43	64	64	1.0	60	56	1.1
	15	0.56	63	59	1.1	65	58	1.1
	16	0.80	58	45	1.3	58	36	1.6
	17	0.94	58	40	1.4	59	31	1.9
C. 0.3 per cent.	18	0.12	70	67	1.0	69	64	1.1
Ni. 3.5 ,,	19	0.27	75	70	1.1	75	66	1.1
Cr. 0.6 ,,	20	0.65	57	6	9.5	58	6	9.7
C. 0.3 per cent.	21	0.26	73	23	3.2	74	20	3.7
Ni. 2.5 ,,	22	0.45	81	15	5.4	83	15	5.5
Cr. 1.6 ,,	23	0.60	81	4	20.2	81	4	20.2
	24	0.91	70	2	35.0	73	2	36.5

The Effect of Phosphorus.

The importance of the influence of phosphorus on susceptibility to temper-brittleness has been pointed out by Dr. J. H. Andrew² and Mr. G. W. Green,³ who have given the following results obtained on a series of 3.5 per cent. nickel steels, containing 0.35 per cent. of carbon, 0.45 per cent. of manganese, and from 0.018 to 0.152 per cent. of phosphorus, oil-hardened from 850° C. and tempered for three hours at 650° C., after which they were either quenched in water or slowly cooled in the furnace, reaching room temperature in two and a half hours.

¹ 635° C. for nickel steels (Nos. 9 to 17).

² *Journal of the Iron and Steel Institute*, 1920, No. I. p. 621.

³ *Ibid.*, 1920, No. II. p. 219.

Phosphorus per Cent.	Izod Impact Figure.		Ratio.	Phosphorus per Cent.	Izod Impact Figure.		Ratio.
	Cooled in Water.	Cooled in Furnace.			Cooled in Water.	Cooled in Furnace.	
0.018	90	93.0	0.97	0.079	84	42.0	2.0
0.039	88	86.6	1.02	0.098	86	8.8	9.8
0.058	84	58.0	1.45	0.152	88	4.6	19.1

These results indicate that the susceptibility of a nickel steel to temper-brittleness is dependent on phosphorus content, and they were supported by further results on nickel-chromium steels containing 0.01 to 0.058 per cent. of phosphorus, taken from actual practice, details of which have, however, not been published. As has already been mentioned, the authors are of the opinion that their own work shows no indication that phosphorus (up to 0.04 per cent.) has a predominating influence in determining the susceptibility of good alloy steels, subject to the ordinary variations of chemical composition. The phosphorus present will doubtless have some effect, but its influence may be entirely masked by that of other variables.

Abnormally high phosphorus content, on the other hand, like abnormally high manganese content, has a marked influence on susceptibility. This is shown by the nickel and the nickel-chromium steels of Tables VI. and VII., the three steels of each

TABLE VI.—*Susceptibility of Nickel Steels (Carbon, 0.33 per Cent. ; Nickel, 3.6 per Cent.) with High Phosphorus Content.*

Izod impact figures after different rates of cooling from the tempering temperature.

No. of Steel.	Phos- phorus per Cent.	Oil-hardened from 900° C.						Oil-hardened from 1000° C.		
		Tempered at 630° C. for 2 Hours and Cooled at the following Rates.								
		In Water.	In Air.	2.5° C. per Minute.	1° C. per Minute.	0.3° C. per Minute.	Suscep- tibility Ratio.	In Water.	0.3° C. per Minute.	Ratio.
25	0.023	75	...	...	...	74	1.0	73	72	1.0
26	0.084	71	58	33	30	30	2.4	72	32	2.3
27	0.144	60	22	13	11	12	5.0	54	10	5.4

TABLE VII.—*Susceptibility of Nickel-Chromium Steels (Carbon, 0.3 per Cent.; Nickel, 3.6 per Cent.; Chromium, 0.7 per Cent.) with High Phosphorus Content.*

Izod impact figures after different rates of cooling from the tempering temperature.

No. of Steel.	Phosphorus per Cent.	Oil-hardened from 900° C.						Oil-hardened from 1000° C.		
		Tempered at 650° C. for 2 Hours and Cooled at the following Rates.								
		In Water.	In Air.	2.5° C. per Minute.	1° C. per Minute.	0.3° C. per Minute.	Susceptibility Ratio.	In Water.	0.3° C. per Minute.	Ratio.
28	0.026	72	69	69	67	65	1.1	69	63	1.1
29	0.090	66	50	17	12	11	6.0	65	10	6.5
30	0.136	58	23	7	6	3	19.3	50	2	25.0

series being almost identical apart from phosphorus content. These results are illustrated in Fig. 6. Dr. Andrew's results are

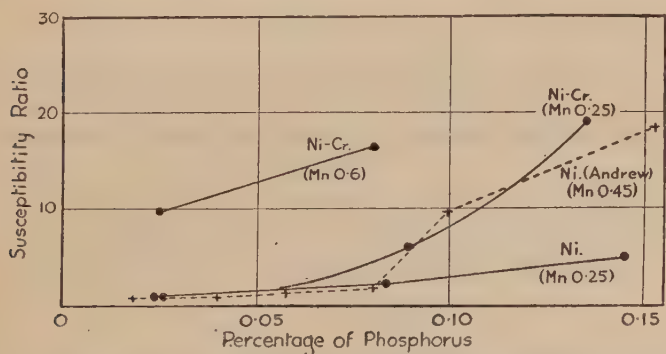


FIG. 6.—Relation between Susceptibility and Phosphorus Content.

plotted in the same diagram, but in comparing them with those now obtained it must be noted that though the rate of slow cooling he employed was quicker, the manganese content of his steels was higher. The impact figures reached by tough and brittle specimens Nos. 27 and 30 of the same high-phosphorus nickel and nickel-chromium steels, heated together at temperatures within the em-

TABLE IX.

Izod impact figures (ft.-lbs.) after reheating the steel in the embrittling range, followed by cooling in water.

Steel 30—Carbon, 0·30 per cent.; nickel, 3·62 per cent.; chromium, 0·70 per cent.; phosphorus, 0·136 per cent.

Oil-hardened from 900° C. and tempered for two hours at 650° C.

Initial tests on the tempered steel before reheating :

Izod impact figures (ft.-lbs.) . . . Tough. Brittle.
56 4

Cooled in Water after—	620° C.	600° C.		575° C.		550° C.		525° C.		500° C.		475° C.	
	Tough.	Tough.	Brittle.	Tough.	Brittle.	Tough.	Brittle.	Tough.	Brittle.	Tough.	Brittle.	Tough.	Brittle.
$\frac{1}{2}$ hr.	...	54	51	35	26	23	13	20	5	...	...	...	...
1 „	56	54	54	32	29	...	...	...	...	...	...	...	...
$1\frac{1}{2}$ hrs.	29	28	19	16	13	6	14	5	15	4
3 „	18	17	...	...	...	...	...	...
4 „	18	18	10	8	11	6	...	...
6 „	9	9	...	...	9	...
8 „	8	7	...	...
10 „	7	7	6	3
16 „	4	4

The Combined Effect of Phosphorus and Manganese.

High manganese and high phosphorus each give rise to increased susceptibility to temper-brittleness, and when both elements are present in abnormal amount each intensifies the action of the other (Table X.).

TABLE X.—*Susceptibility of Nickel-Chromium Steels (Carbon, 0·3 per Cent.; Nickel, 3·6 per Cent.; Chromium, 0·7 per Cent.) with Varying Manganese and Phosphorus Contents.*

Izod impact figures (ft.-lbs.).

No. of Steel.	Manganese per Cent.	Phosphorus per Cent.	Oil-hardened from 900° C.			Oil-hardened from 1000° C.		
			Tempered at 650° C. for 2 Hours and Cooled.					
			In Water.	0·3° C. per Minute.	Ratio.	In Water.	0·3° C. per Minute.	Ratio.
28	0·23	0·026	72	65	1·1	69	63	1·1
29	0·24	0·090	66	11	6·0	65	10	6·5
20	0·65	0·025	57	6	9·5	58	6	9·7
31	0·53	0·079	66	4	16·5	64	3	21·3

The Effect of Silicon.

The only high-silicon nickel steel examined gave an indication that silicon tends to increase susceptibility to temper-brittleness, but not to an important extent in steels within the ordinary limits of variation of silicon content. A high-silicon carbon steel showed about the same susceptibility as might be expected from a similar steel with equal manganese content and low silicon (Table XI.). In silicon-manganese steels the silicon is unlikely to reduce, and will probably reinforce, the effect of the manganese in inducing susceptibility.

TABLE XI.—*Susceptibility of Carbon and Nickel Steels with High Silicon Content.*

Izod impact figures (ft.-lbs.).

No. of Steel.	Carbon per Cent.	Manganese per Cent.	Silicon per Cent.	Nickel per Cent.	Oil-hardened from 900° C.			Oil-hardened from 1000° C.		
					Tempered at 635° C. for 2 Hours and Cooled.					
					In Water.	0·3° C. per Minute.	Ratio.	In Water.	0·3° C. per Minute.	Ratio.
15	0·41	0·56	0·05	3·94	63	59	1·1	65	58	1·1
32	0·42	0·49	1·34	3·32	54	23	2·3	51	18	2·8
33	0·59	0·65	1·85	...	42	36	1·2	42	34	1·2

The Effect of Vanadium.

A number of chromium, nickel, and nickel-chromium steels containing vanadium have been examined. In the series of crucible steels investigated the influence of vanadium on the susceptibility to temper-brittleness was slight. The results given in Table XII. show a small and unimportant increase in susceptibility when vanadium is present. They definitely indicate, however, that vanadium shows no tendency to reduce susceptibility or to render steels non-susceptible to temper-brittleness. This conclusion is confirmed by the fact that some samples of acid

open-hearth nickel-chromium-vanadium steels are among the most susceptible of the steels examined (Table XIII.), while

TABLE XII.—*Susceptibility of Steels containing Vanadium.*
Izod impact figures (ft.-lbs.).

Type of Steel.	No. of Steel.	Vanadium per Cent.	Oil-hardened from 900° C.			Oil-hardened from 1000° C.		
			Tempered at 650° C. ¹ for 2 Hours and Cooled.					
			In Water.	0·3° C. per Minute.	Ratio.	In Water.	0·3° C. per Minute.	Ratio.
C. 0·34 per cent.	9	nil	68	67	1·0	17	70	1·0
Ni. 2·6 ,,	34	0·38	66	61	1·1	32	23	1·4
	35	0·61	60	45	1·3	35	25	1·4
C. 0·33 per cent.	36	nil	53	49	1·1	46	40	1·2
Cr. 0·64 ,,	37	0·39	49	48	1·0	16	13	1·2
	38	0·63	37	33	1·1	15	10	1·5
C. 0·35 per cent.	6	nil	66	62	1·1	59	41	1·4
Cr. 1·2 ,,	39	0·38	58	38	1·5	19	9	2·1
	40	0·68	61	41	1·5	15	8	1·9
C. 0·35 per cent.	53	nil	70	65	1·1	70	62	1·1
Ni. 2·6 ,,	41	0·36	54	50	1·1	36	28	1·3
Cr. 0·65 ,,	42	0·68	51	46	1·1	33	14	2·4
C. 0·33 per cent.	43	nil	60	57	1·1	57	44	1·3
Ni. 2·6 ,,	44	0·34	48	30	1·6	31	12	2·6
Cr. 1·2 ,,	45	0·61	46	29	1·6	31	10	3·1
C. 0·4 per cent.	57	nil	66	35	1·9	68	34	2·0
Ni. 2·6 ,,	46	0·37	39	21	1·9	29	11	2·6
Cr. 1·2 ,,	47	0·65	35	20	1·8	29	10	2·9
C. 0·32 per cent.	...	...	...	...	...	...	...	...
Ni. 5·1 ,,	48	0·36	39	25	1·6	27	14	1·9
Cr. 0·6 ,,	49	0·61	36	19	1·9	22	10	2·2

Note.—These figures should not be used for making a direct comparison of the behaviour of the steels in the notched-bar test, since identical treatment left the steels containing vanadium in a much harder condition than those without vanadium: also, many of the steels hardened from 1000° C. showed greater hardness after tempering than those hardened from 900° C.

chromium-vanadium steels are well known to show temper-brittleness.²

¹ 635° C. for the nickel-chromium-vanadium steels with 5 per cent. nickel (Nos. 48 and 49).

² *Journal of the Iron and Steel Institute*, 1920, No. II. p. 198.

TABLE XIII.—*Susceptibility of Acid Open-Hearth Nickel-Chromium-Vanadium Steels.*

	C.	Si.	Mn.	S.	P.	Ni.	Cr.	V.
(A)	0.35	0.20	0.32	0.035	0.036	3.76	1.09	0.28
(B)	0.28	0.27	0.36	0.035	0.030	5.16	0.69	0.34

Steel.	Oil-hardened from 900° C.			Oil-hardened from 1000° C.		
	Tempered, Steel A at 650° C., Steel B at 635° C., for 2 Hours and Cooled.					
	In Water.	0.3° C. per Minute.	Ratio.	In Water.	0.3° C. per Minute.	Ratio.
A	41	3	13.7	36	1	36.0
B	35	3	11.7	38	2	19.0

The Effect of Tungsten.

Similar information has been obtained in the course of work carried out on twenty-two carbon, nickel, and nickel-chromium steels covering a similar range of composition, but containing, instead of vanadium, tungsten up to 2.4 per cent. in nickel steels and up to 1.7 per cent. in carbon and in nickel-chromium steels. The presence of tungsten caused no appreciable change in the susceptibility. Non-susceptible carbon and nickel steels remained non-susceptible, slightly susceptible nickel-chromium steels remained susceptible to about the same degree.

Only one electric furnace nickel-tungsten steel and one acid open-hearth nickel-chromium-tungsten steel have been examined. These contained—

C.	Si.	Mn.	S.	P.	Ni.	Cr.	W.
0.43	0.27	0.40	0.009	0.025	2.97	...	2.00
0.35	0.24	0.38	0.033	0.027	3.58	0.79	1.83

and showed susceptibility ratios of 1.1 and 4.2, the corresponding ratios after hardening from 1000° C. being 1.3 and 7.0 respectively.

The Effect of Molybdenum.

The addition of molybdenum exercises a very powerful influence in reducing, or in some cases apparently eliminating,

susceptibility to temper-brittleness. This is clear from the tests on acid open-hearth steels containing molybdenum already referred to, and reproduced in Table XIV. These steels, judged by the results of the standard treatment, are non-susceptible. The ratio 0.97 to 1.06 which they consistently show is in marked contrast to the values shown by other acid open-hearth alloy steels not containing molybdenum.

The effect of molybdenum has been studied in a series of twenty-three crucible steels covering the following wide limits of percentage composition :

Type of Steel.	Carbon.	Nickel.	Chromium.	Molybdenum.
Carbon steels . . .	0.3	...	...	0 to 1.2
Nickel steels . . .	0.3	2.8	...	0,, 1.0
Chromium steels . . .	0.3	...	1.0	0,, 1.0
" " " " . . .	0.3	...	2.0	0,, 0.5
Nickel-chromium steels .	0.35	1.7	1.1	0,, 1.0
" " " " .	0.35	2.7	0.6	0,, 1.0
" " " " .	0.33	2.8	1.2	0,, 0.6
" " " " .	0.27	2.7	1.0	0,, 1.0

These steels contained manganese 0.14 to 0.31 per cent. and phosphorus 0.022 to 0.040 per cent.

The chromium and nickel-chromium steels without molybdenum were slightly but distinctly susceptible to temper-brittleness, but in every case steels with 0.3 per cent. of molybdenum and over showed no temper-brittleness—*i.e.* a susceptibility ratio of 1.0, whether quenched from 900° C. or 1000° C. The biggest difference in the average impact figure between steels cooled in water after tempering and those slowly cooled was within the ordinary limits of variation for any one steel. In an endeavour to obtain a low impact figure from nickel-chromium-molybdenum steels as a result of temper-brittleness, a variety of abnormal treatments was applied to them in cooling from the tempering temperature. For example, some of the hardened and tempered steels were reheated to 600° C. and cooled very slowly, the rate of cooling from 600° to 400° C. being 1° in sixteen minutes. This treatment had no effect in reducing the impact figure of the steels containing molybdenum (Table XV.). A treatment involving

heating for seven days at 450° C. following an extremely slow cooling from 600° to 450° C. was no more effective.

TABLE XIV.—*Susceptibility of Acid Open-Hearth Nickel-Chromium-Molybdenum Steels.*

	C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.
(A)	0.28	0.15	0.48	0.032	0.028	2.45	0.65	0.43
(B)	0.25	0.10	0.49	0.040	0.035	2.84	0.85	0.48
(C)	0.29	0.14	0.48	0.032	0.026	2.47	0.64	0.47
(D)	0.32	0.16	0.55	0.034	0.028	2.37	0.63	0.70
(E)	0.34	0.12	0.44	0.030	0.030	2.39	0.72	0.57
(F)	0.40	0.14	0.63	0.031	0.028	3.54	0.32	0.27

Steel.	Oil-hardened from 900° C.			Oil-hardened from 1000° C.		
	Tempered at 650° C. for 2 Hours and Cooled.					
	In Water.	0.3° C. per Minute.	Ratio.	In Water.	0.3° C. per Minute.	Ratio.
A	58	57	1.02	57	59	0.97
B	37	35	1.06	36	37	0.97
C	65	64	1.02	...	...	...
D	44	44	1.00	...	...	...
E	46	44	1.05	...	...	...
F	39	37	1.05	...	...	...

The influence of molybdenum in reducing the susceptibility to temper-brittleness of steels containing abnormally high manganese or phosphorus content is clearly shown by the results given in Tables XVI. and XVII. No advantage appears to be gained by adding more than 0.5 per cent. of molybdenum. Molybdenum does not eliminate, but greatly reduces, the susceptibility of nickel-chromium steels with high phosphorus or manganese content. It is therefore desirable to limit these elements to the maxima usual for nickel-chromium steel, though when molybdenum is present the steels remain practically non-susceptible when manganese or phosphorus content is abnormally high. This is shown by the behaviour of steels 60 to 63 (Table XVII.), and also by the results showing the effect of increasing the percentage of manganese in a nickel-chromium-molybdenum steel (Table XVIII.).

TABLE XV.—*Susceptibility of Nickel-Chromium Steels containing Molybdenum.*

Izod impact figures (ft.-lbs.).

No. of Steel.	Type of Steel.	Molybdenum per Cent.	Oil-hardened from 900° C.			Oil-hardened from 1000° C.			Oil-hardened from 900° C.		
			Tempered for 2 Hours at 650° C.								
			Cooled.			Cooled.			Reheated to 600° C. and Cooled.		
			In Water.	0·3° C. per Minute.	Ratio.	In Water.	0·3° C. per Minute.	Ratio.	In Water.	1° C. in 16 Minutes.	Ratio.
50	Per Cent. C. 0·35	nil	67	65	1·03	70	62	1·13	67	48	1·40
51	Ni. 1·7	0·61	54	55	0·98	54	54	1·00	54	53	1·02
52	Cr. 1·1	1·06	44	45	0·98	44	45	0·98	...	...	...
53	C. 0·35	nil	70	65	1·07	70	62	1·13	66	60	1·10
54	Ni. 2·7	0·37	...	...	...	...	...	...	53	54	0·98
55	Cr. 0·6	0·57	54	53	1·02	54	53	1·02	54	53	1·02
56		1·01	48	48	1·00	48	47	1·02	48	47	1·02
57	C. 0·3	nil	66	35	1·89	68	34	2·00	66	26	2·54
58	Ni. 2·8 Cr. 1·2	0·58	47	48	0·98	47	47	1·00	47	47	1·00

TABLE XVI.—*Effect of Molybdenum on the Susceptibility of a 2 per Cent. Manganese Steel.*

Izod impact figures (ft.-lbs.).

No. of Steel.	Carbon per Cent.	Manganese per Cent.	Molybdenum per Cent.	Oil-hardened from 900° C.		Oil-hardened from 1000° C.			
				Tempered at 650° C. for 2 Hours and Cooled.					
				In Water.	0·3° C. per Minute.	Ratio.	In Water.	0·3° C. per Minute.	Ratio.
3	0·36	2·24	nil	74	4	18·5	...	...	...
59	0·30	2·30	0·52	59	50	1·2	60	40	1·5

TABLE XVII.—*Effect of Molybdenum on the Susceptibility of Nickel-Chromium Steels containing High Phosphorus or Manganese (Carbon, 0.3 per Cent. ; Nickel, 3.6 per Cent. ; Chromium, 0.7 per Cent.).*

Izod impact figures (ft.-lbs.).

No. of Steel.	Manganese per Cent.	Phosphorus per Cent.	Molybdenum per Cent.	Oil-hardened from 900° C.			Oil-hardened from 1000° C.		
				Tempered at 650° C. for 2 Hours and Cooled.					
				In Water.	0.3° C. per Minute.	Ratio.	In Water.	0.3° C. per Minute.	Ratio.
29	0.24	0.090	nil	66	11	6.0	65	10	6.5
60	0.16	0.070	0.38	61	55	1.1	59	54	1.1
61	0.18	0.074	0.59	49	37	1.3	48	38	1.3
20	0.65	0.025	nil	57	6	9.5	58	6	9.7
62	0.84	0.024	0.34	57	45	1.3	54	42	1.3
63	0.72	0.034	0.65	52	29	1.8	48	19	2.5

TABLE XVIII.—*Effect of Manganese on the Susceptibility of Nickel-Chromium-Molybdenum Steel (Carbon, about 0.3 per Cent. ; Nickel, 2.6 per Cent. ; Chromium, 0.6 per Cent. ; Molybdenum, 0.6 per Cent.).*

(Compare with the much greater effect on nickel-chromium steel, Table V.)

Izod impact figures (ft.-lbs.).

No. of Steel.	Manganese per Cent.	Oil-hardened from 900° C.			Oil-hardened from 1000° C.		
		Tempered for 2 Hours at 650° C. and Cooled.					
		In Water.	0.3° C. per Minute.	Ratio.	In Water.	0.3° C. per Minute.	Ratio.
55	0.17	54	53	1.02	54	53	1.02
64	0.64	58	51	1.14	58	51	1.14

DISCUSSION OF RESULTS.

1. Susceptibility to temper-brittleness is shown by the series of experiments described above, and by other work, to be markedly influenced by differences in composition. Phosphorus and manganese increase susceptibility, and when they are present in any amount beyond a small percentage the increase is very

pronounced. Silicon and vanadium have a slight effect, and tungsten no appreciable effect, in increasing susceptibility, when present in percentages likely to be met with in commercial steels ; but it seems clear that none of these three elements will inhibit temper-brittleness. Molybdenum, on the other hand, has a very pronounced effect in reducing susceptibility, and a small percentage of molybdenum (about 0·3 to 0·5 per cent.) counteracts the influence of high phosphorus and manganese in this respect, and renders steels, which are normal in composition as regards these elements, non-susceptible. More extended use of molybdenum is a means, and may prove to be the best method, of overcoming difficulties associated with temper-brittleness.

2. Susceptible steels may, in other respects, be very satisfactory, and after proper treatment may show excellent mechanical properties. Such, for example, are the high-manganese carbon steels, and nickel-chromium steels with relatively high carbon and chromium content. Yet, in these steels, air-cooling of fairly large masses from the tempering temperature may often give rise to very low impact figures. The undesirable temper-brittle condition may be avoided by cooling in water from the tempering temperature, but objections have been urged to this procedure on the ground that severe internal stresses are produced. That internal stresses are set up by rapid cooling after tempering is shown by the depression of the elastic limit in water-cooled specimens,¹ and in certain circumstances these stresses may be serious in amount. They might be eliminated if it were possible to adopt water-cooling, interrupted at about 400° C. by withdrawal of the steel after it had passed through the embrittling range.

Serious internal stresses may be avoided by the use of a somewhat slower rate of cooling, such as quenching in oil, in which the rate of cooling is considerably checked before the steel cools below 300° C., or they may be relieved without detriment to the properties by reheating to a temperature of 400° C. The impact figure of a steel in the tough condition is not affected by a short treatment at this temperature. To produce a 20 per cent. fall from maximum impact figure in the steel, of which the range is shown in Fig. 1, a treatment for two hours at 450° C. or for 141 days at 350° C.¹ was required.

¹ *Journal of the Iron and Steel Institute*, 1920, No. II. p. 213.

3. The specific volume of the water-cooled steel is greater than that of the steel slowly cooled from the tempering temperature, but, on heating, shrinkage occurs at temperatures below that at which the impact figure is affected.²

So far as is known no appreciable volume change accompanies the transformation from the tough to the brittle condition on cooling through the embrittling range, and the intensity of internal stress in the water-cooled steel is due only to inequalities of thermal contraction induced by the temperature gradient set up. It is likely to be smaller, the lower the temperature from which water-cooling is carried out. If the initial tempering temperature is high, it may be advisable to cool after initial tempering not faster than in air, and subsequently to reheat and cool in water. The reheating does not affect the tensile properties if carried out at a temperature well below that of the initial tempering.

4. The diagram, Fig. 8, shows the temperatures of reheating, followed by cooling in water, which produced (a) a fall of 20 per cent. in impact figure from the maximum shown by the steel in the tough condition, and (b) a rise of 20 per cent. in the impact figure of the steel in the brittle condition. This diagram indicates the position of the embrittling range for all the steels of which the range has been determined in the Research Department, Woolwich. The steels vary in susceptibility from 1.9 to 26.0. It is clear that in a steel showing no temper-brittleness (*i.e.* susceptibility 1.0) the embrittling range cannot be determined. This may be because it is non-existent, or because it occurs at so low a temperature that the change is suppressed. It is true that low susceptibility is associated with a low range, but there is no indication of a sudden downward tendency which would bring the upper limit of the range in a practically non-susceptible steel to below, say, 500° C. On the other hand, non-susceptible nickel-chromium-molybdenum steels have been found to give the same impact figure after a slow cooling, which involved holding for seven days at 450° C., as in the water-cooled condition. If the range is existent in these steels, its upper limit must be below 450° C. On the whole, it seems that the non-existence of an embrittling range in these steels is more probable than its depression to a low temperature.

¹ *Journal of the Iron and Steel Institute*, 1920, No. II. p. 177.

² *Ibid.*, 1919, No. II. p. 393; 1920, No. II. p. 210.

For the purpose of restoring the impact figure of a hardened and tempered steel,¹ it is unsafe to reheat a temper-brittle steel at a temperature below 600° C. and rapidly cool, unless the

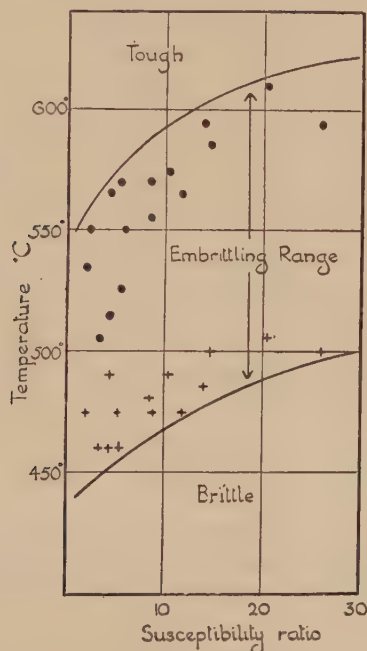


FIG. 8.—Position of the Embrittling Range.

- Temperature at which there is a 20 per cent. fall in the tough figure.
 + " " " " " rise " brittle "

position of the embrittling range is well known. Some steels, even after treatment at that temperature, may fail to reach 80 per cent. of the maximum impact figure which they are capable of giving without detriment to their tensile properties.

[The Discussion and Correspondence on this paper will be found on p. 261.]

¹ The effect of giving a hardened steel which is susceptible to temper-brittleness an *initial* tempering within the embrittling range is complicated by the fact that the softening and the embrittling tendencies exercise opposite influences on the impact figure. In the early stages of tempering the former outweighs the latter, but subsequently the impact figure begins to fall, and may eventually reach a low value (see *Journal of the Iron and Steel Institute*, 1920, No. II. pp. 182-188).

Iron and Steel Institute.

NOTE ON NITROGEN AS A POSSIBLE FACTOR IN TEMPER-BRITTLENESS.*

By W. T. GRIFFITHS, M.Sc., F.I.C., A.Inst.P. (WOOLWICH).

It has been pointed out by certain investigators^(1, 2, 3, 4) that in a steel which exhibits susceptibility to temper-brittleness, different magnetic properties may be associated with the high and the low notched-bar impact figures shown by the steel after quick and slow cooling from the tempering temperature. While considering the possibility of using the rate of change of some magnetic property with change of temperature as an indication of the position of the so-called "embrittling range" in temper-brittle steels, the author was struck by the fact that steels containing nitrogen were said to show magnetic changes at a somewhat similar temperature to those stated to mark the beginning and end of this range.^(5, 6)

Further investigation showed that after increasing the nitrogen content in certain steels which were non-susceptible to temper-brittleness, an effect could be produced on the impact figure of the steel, by quickly or slowly cooling from 630° or 650° C., which was apparently identical with that characteristic of temper-brittle steels. A carbon steel of the composition—

Carbon per Cent.	Silicon per Cent.	Manganese per Cent.	Sulphur per Cent.	Phosphorus per Cent.	Nitrogen per Cent.
0.39	0.093	0.57	0.020	0.025	0.004

and non-susceptible to temper-brittleness was used for the first experiments. After hardening from 900° C. and tempering at 650° C., specimens quickly and slowly cooled gave impact figures of 52 and 50 respectively.

(a) A piece of the steel, $4\frac{1}{4}$ in. \times 1 in. \times $\frac{1}{2}$ in., was quenched in water from 900° C. and then heated in a wire-wound tube furnace at 600° C. for five hours, dry ammonia being passed over it. The specimen was divided into two pieces, each $4\frac{1}{4}$ in. \times $\frac{1}{2}$ in. \times $\frac{1}{2}$ in., which were heated in air in a muffle furnace at 650° C. for two hours; one piece was then quenched in water and the

* Communication from Research Department, Woolwich.

other cooled in the furnace at a rate of 0.3° C. per minute. Both specimens were machined to standard 10×10 millimetres Izod test-pieces. The highly nitrified skin was removed in the course of machining, and the notches were cut on the face which had not been exposed to the ammonia. Thus the test-piece contained only the small amount of nitrogen which had diffused inwards. (Average nitrogen content now 0.015 per cent.) The average Izod impact figures were :

After water-cooling from 650° C.	35 ft.-lbs.
After slowly cooling from 650° C.	20 „

(b) A similar specimen of the same steel was heated in ammonia for thirty hours at 630° C. It was divided longitudinally as before, and the pieces were hardened by heating in air at 900° C. for one hour and quenching in water. They were then tempered at 650° C., cooled, and machined as described above. The average Izod impact figures were :

After water-cooling from 650° C.	30 ft.-lbs.
After slowly cooling from 650° C.	12 „

The Brinell hardness of both test-pieces was 173.

(c) Another specimen was given a similar treatment to the last, but with nitrogen replacing the ammonia, thus avoiding oxidation but introducing no nitrogen into the steel. Identical impact figures (63 ft.-lbs.) were obtained after final water-cooling and slow cooling, showing that the differences previously obtained were not due merely to the prolonged heating at 630° C. before quenching and tempering.

(d) A non-susceptible nickel steel of the composition—

Carbon per Cent.	Silicon per Cent.	Manganese per Cent.	Sulphur per Cent.	Phosphorus per Cent.	Nickel per Cent.	Nitrogen per Cent.
0.31	0.06	0.17	0.024	0.023	3.67	0.006

was heated first to 850° C. for one hour in an atmosphere of nitrogen, and was then cooled rapidly in the furnace to 710° C. The nitrogen was replaced by ammonia and the steel held at 700° to 710° C. for forty-eight hours in a stream of this gas. After cooling in the furnace to room temperature, specimens cut for further treatment were oil-hardened from 900° C., tempered at 630° C. for two hours, one being cooled in water and the other

slowly cooled at 0.3° C. per minute. The average Izod impact figures and Brinell hardness numbers were :

After water-cooling from 630° C. . . .	81 ft.-lbs. and 193 *
After slowly cooling from 630° C. . . .	49 „ „ 188

Specimens of the same steel into which no nitrogen had been introduced, after oil-hardening from 900° C. and tempering, gave Izod impact figures :

After water-cooling from 630° C. . . .	75 ft.-lbs.
After slowly cooling from 630° C. . . .	74 „

The fractures of all specimens containing nitrogen water-cooled after tempering were fibrous, but those of the slowly cooled test-pieces were of the usual bright granular type of temper-brittle material. No differences were observed in the microstructure of test-pieces giving the higher and lower impact figures, and it will be seen that the Brinell hardness numbers of the two are similar.

These results may be accounted for if, as indicated by several investigators,^(5, 7, 8) the nitride phases free at room temperatures pass into solution on heating to temperatures above 600° C. and are retained in solution on water-cooling from those temperatures, though they separate again on slow cooling. Referring to the needles of "nitride" † present in nitrified steels, Fry states that "on quenching from temperatures above 450° C. the needles decrease and go on lessening as the temperature from which quenching is carried out is raised; when a temperature of 580° is reached the nitride needles remain entirely in solution."

These temperatures, it will be noticed, are in substantial agreement with those marking the beginning and the end of the embrittling range, and if the nitride phases are in equilibrium with each other at each temperature, properties such as those exhibited by steels susceptible to temper-brittleness may be expected in steels water-cooled from temperatures between and above those mentioned.

Attempts to introduce nitrogen into alloy steels other than

* Further work on this steel, carried out after recording the above, shows that the relation of the Izod figures after water-cooling from 630° , and after slow cooling from that temperature, is considerably affected by slight variations in the conditions of the previous treatments. The causes of the variations in the figures have not yet been exactly determined.

† Fry is of opinion that the needles are not pure nitride, but a solid solution containing more nitride than the surrounding ferrite.

the nickel steel mentioned above have, up to the present, been unsuccessful. The rate of diffusion of nitrogen into these steels at any temperature suitable for nitrification with ammonia is extremely slow—hard, highly nitrified surface layers forming without the centre of the specimen being affected.

It however appears from what has been done that nitrogen may in certain circumstances exert an important influence on the susceptibility of a steel to temper-brittleness.

It has been stated that, when phosphorus and manganese contents are low, differences in susceptibility, apparently unconnected with chemical composition, but more probably depending on the method of manufacture, are sometimes found. The unknown factor in these instances may possibly be nitrogen content, which is known to vary not only with method of manufacture, but also by reason of additions made to the steel. Tschischewski⁽⁷⁾ has shown that nitrogen may be introduced in combination with manganese, silicon, or aluminium, which are employed in different relative quantities in different steel-making processes.

To determine the possible influence of nitrogen on susceptibility to temper-brittleness, or to elucidate the analogous effect revealed by the results described above, will require much further investigation. These experimental observations are, however, brought before the Institute at this stage, as they are thought to be of interest in connection with the question of the effect of composition on the susceptibility of steel to temper-brittleness, a subject which is being dealt with in another paper presented at this meeting.

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DISCUSSION.

Dr. W. H. HATFIELD (Sheffield), in opening the discussion on the two papers, said both were of interest to the Institute, dealing, as they did, with one of the most difficult subjects with which the Institute had at any time had to deal, namely, the notch-bar test. He had to take exception to the expressions, "tough steels" and "brittle steels," used by the authors; they should have spoken of "notch tough steels" and "notch brittle steels," because the types of brittleness to which they were referring were only disclosed when a notch was made in a piece of steel. He hoped they would accept that correction. The paper by Mr. Greaves and Mr. Jones was a very real and serious contribution to the subject, and he did not think anyone present who had carefully investigated the subject could take exception to the experimental evidence which had been put forward. For his own part, however, he would have preferred that that experimental evidence should have been amplified by the very necessary data which should be given for an adequate consideration of the results obtained from an isolated formal test without any other information as a means of correlation; that was, the Brinell tests should be given as well as the impact tests. It would have been a great advantage to have also the tensile as well as the Brinell and impact tests, because, when there were variations in impact value, those variations were due to heat treatment, and it was always well to be sure that the balance of the other physical characteristics were in accord with the condition which was postulated by the results from that particular test. For instance, in Table V. in the paper the first three steels had 0.4 per cent. of carbon and 1.6 per cent. of chromium, but the manganese increased from 0.22 per cent. to 0.60 per cent. to 0.91 per cent. The authors had, nevertheless, submitted three steels of such widely divergent composition to the same tempering temperature. It would, of course, entail a great deal of work, but it was necessary to carry through the scheme the authors had in mind, and the deductions from that experimental work would have been much more valuable had they taken each composition and, by pilot heat treatments, determined the necessarily differing tempering temperatures for the three steels. The authors had not done so, and that had decreased the value of the data they had supplied.

He was very pleased to see the whole-hearted confession by the authors in the paper that the means adopted in manufacture for the introduction of a high impact or notch-tough condition, namely, quenching in water from the tempering temperature, led to dangerous internal stress. The engineering world could not give too much attention to that somewhat belated confession. In the introduction of high impact value into steel by water-quenching, serious internal stresses were certainly left in steel, and it was very gratifying to see that the authors had at last realised that fact. Their data must, he thought, be

accepted as indicating the influence of varying composition upon the ability of steel to possess, under certain conditions of treatment, either a high or a low impact value; but he very much questioned whether the remedy was quite as simple as the authors suggested. The real deduction from the paper was that if 0.3 to 0.5 per cent. of molybdenum was added to steel, there would be produced a steel of which the impact value would not vary under different rates of cooling. There was a lot of truth in that, but molybdenum did not invariably have that action, and, furthermore, the addition of molybdenum did not induce high impact value. Many of the classes of steel to which the authors referred, to which 0.3 to 0.5 per cent. of molybdenum was added, would give a maximum impact value under treatment condition of 30 to 50 ft.-lbs., which was not a high impact value. He agreed that, generally speaking, slow cooling did not lower that impact value to an abnormally low value, but there were exceptions. Molybdenum was an extremely expensive material, and from an industrial point of view a recommendation which involved a material increase in the cost of steel incurred merely to eradicate a disability which was of no real industrial consequence, was not to be recommended. For exceptional purposes, where very high tensile strength with considerable ductility was required, the expenditure of a considerable sum of money on molybdenum content was well justified. He did not say that with reference to the impact tests, but with reference to the fact that, if a high tensile alloy steel was being produced in which a great tensile strength was required—that was, in which the steel in its final condition was in an exceptionally hard condition—the influence of molybdenum was to increase the ductility for a given tonnage, using the word “ductility” in the sense in which it was usually understood, namely, elongation and reduction of area. Molybdenum had a very real influence in that respect.

With regard to the paper by Mr. Griffiths, he thought the author would be content if they accepted his paper as a very interesting and carefully conducted investigation for information purposes, but hardly of industrial interest, since the nitrogen content in commercial steels was well understood, and was of such an order as not to influence the mechanical characteristics of the material. In conclusion, he would like to say how much they appreciated those papers from Woolwich Arsenal from time to time. Woolwich Arsenal, by its research work, was contributing very considerably to the metallurgy of steel.

CORRESPONDENCE.

Mr. T. E. ROONEY (Teddington) wrote that he was interested in the results obtained by the authors, more especially as they had given in Table I. a fairly complete range of compositions.

In view of the fact that Mr. Griffiths had found that a small percentage of nitrogen would give rise in a nickel-chromium steel to a condition analogous to temper-brittleness, it would be interesting to know

if, in the analysis of steels used in the research, any attention was paid to the fact that, in estimating the sulphur content in certain nickel-chromium steels, evolution methods were not reliable, as the results obtained were often much lower than the results obtained by the gravimetric method. He (Mr. Rooney) had carried out some research on the estimation of sulphur in nickel-chromium steels, and had found that, where a low result was obtained by the evolution method, a microscopical examination of a polished specimen revealed the fact that two constituents were present in the non-metallic inclusions. Experimental melts were made with the addition of varying amounts of manganese, and it was found that the addition of manganese tended to produce a steel in which the non-metallic inclusions did not appear to contain two constituents, and also the percentage of sulphur obtained by the evolution method approximated more closely to that obtained by the gravimetric method.

Nickel-Chromium Steels.

Manganese.	Sulphur.	
	Evolution Method.	Gravimetric Method.
Per Cent.	Per Cent.	Per Cent.
0·01	0·040	0·072
0·05	0·034	0·073
0·09	0·014	0·054
0·27	0·038	0·064
0·39	0·036	0·060
1·02	0·055	0·063
2·30	0·068	0·067

As the authors had found that high manganese content had a marked influence on the susceptibility of steels to temper-brittleness, it might be of interest to have some information as to the character of the inclusions in the steels used by them, and also if the addition of molybdenum resulted in any marked change in their character.

The character of the inclusions was not entirely influenced by the amount of manganese present, as he (Mr. Rooney) had examined a number of nickel-chromium steels of varying manganese content, the inclusions in which appeared to contain only one constituent when examined under the microscope; also the percentage of sulphur as estimated by the evolution and gravimetric methods was the same in each case.

Messrs. R. H. GREAVES and J. A. JONES, in reply, wrote that they accepted the limitation implied by Dr. Hatfield in the terms "notch toughness" and "notch brittleness." The matter had been made quite clear in the paper, where notched-bar tests only were referred to. A great deal of additional information asked for by Dr. Hatfield already existed, and was to be found in the publications of the Research Department and the other publications referred to in the footnotes to

the paper, but many of the tests suggested by Dr. Hatfield had necessarily been omitted in order to narrow down the scope of the paper, which would otherwise have grown to a very great length. There was no doubt that internal stresses were produced by water-quenching; that had been indicated in a previous paper, where it had been pointed out that the elastic limit of quenched material was lower than that of slowly cooled material. The extent of the internal stresses depended to a great extent on the material which was being treated, and in a forging of uniform cross-section they were probably not serious, though in some forms of forging they might be considerable. In the paper they had only referred to molybdenum steel with reference to the influence of molybdenum on temper-brittleness; they did not say that all molybdenum steels were of the highest quality. Discrimination was necessary both with regard to composition and heat treatment, but their experience was quite definite, that, in every case they had tried, molybdenum had had the effect of practically eliminating temper-brittleness. They would be very pleased to hear of, and to investigate, other compositions in which that was not the case.

In reply to Mr. Rooney, they stated that sulphur was, in all instances, estimated by the gravimetric method. The steels were relatively free from inclusions, and the addition of molybdenum made no apparent difference in their character. As, however, the authors had not carried out any special investigation of the inclusions present, they did not feel justified in making any general statement as to their nature.

Mr. W. T. GRIFFITHS, replying, said he was not convinced that, because the nitrogen content of commercial steel was small, the effect of nitrogen could therefore be neglected, as Dr. Hatfield said. Temper-brittleness was a trouble for which, up to the present, no convincing explanation had been found, and it would be unwise to pass over without consideration any possible cause. The phenomenon could be explained by the passing into solution of something at temperatures below the Ac point, its retention in solution on quickly cooling, and its precipitation on slow cooling. Further, it had been pointed out on several occasions in previous discussions that the separation would probably be that of ultramicroscopic particles of a hard brittle phase, so that no great quantity needed to be present to give this effect. Nitrogen fulfilled those conditions in steel, and also had been shown to produce effects similar to temper-brittleness; therefore the presence of even small percentages should not be overlooked in this connection.

At the same time he quite agreed that nitrogen might have nothing to do with temper-brittleness, and would only suggest that the effect shown by nitrogen might be exhibited by some other impurity even though present in small quantity. If his paper had the effect of emphasising the point that not even the smallest traces of an impurity could safely be disregarded, he would feel amply repaid for its preparation.

Iron and Steel Institute.

PEELING IN WHITE-HEART MALLEABLE.

By DOUGLAS H. INGALL, M.Sc.
(COUNTY TECHNICAL COLLEGE, WEDNESBURY),

AND

H. FIELD (WILLENHALL).

SECTION I.—INTRODUCTION.

THE phenomenon of "peeling" with which this paper deals is a defect well known both to malleable ironfounders and machinists, being met with frequently in the manufacture and use of malleable cast iron.

Castings suffering from this defect present a normal outward appearance, but the fracture after breaking reveals an inner core, surrounded by one or more layers of "skin" or "peel," these layers being so loosely attached to the core and to one another that either they become detached in the breaking or can be removed by a few blows with a hammer. The remaining core then presents a smooth surface, and has generally the same contour as the original specimen. Fractures of "peeled" malleable iron are illustrated in Fig. 3 (Plate XXXI.), which shows the separated peel in one part and the remaining core at another.

The mechanical properties of the metal are not greatly affected by the presence of this internal defect, except in cases where it may be very pronounced, notably thin plates, where the core may be entirely absent and the metal a series only of "skins." In breaking tensile test-bars or in bending tests it is noticed that both skin and core elongate together for a time, after which the skin begins to crack and part from the core. The trouble with "peeled" castings arises when they are machined, as either in planing or screwing the entire skin may come away from the core, or in milder cases the threads peel off as a string. Smaller castings which are not machined are often water-barrelled before plating, and this prolonged process sometimes wears right through the outer skin at one place and the whole then peels off.

One of the authors, engaged in the production of malleable

castings, came frequently across such defective castings, and an attempt was made to locate the faulty procedure involved, although no formula was found which satisfied every case. It became apparent that the question was one for systematic research, and the method chosen—as shown in another part of the paper—has been to reproduce the phenomenon under known conditions.

In works practice it has been found that the trouble can be attributed to a large number of causes, and in fact at different times it has been accounted for as due to variation in almost any and every part of the process. References in published work are very scanty, and so far as the authors are aware there are none in any of the foundry text-books. In the discussion of a paper by Hurren¹ various speakers spoke of peeling as due to (a) the oven having its temperature raised too quickly; (b) high manganese content; (c) high sulphur content; (d) too high annealing temperature; (e) too strong annealing ore.

W. H. Poole² describes the phenomenon carefully, and formulates a theory, as also does J. W. Gardom,³ both of these writers attributing the defect to a rate of carbon elimination at the surface more rapid than that of the diffusion of carbon within the casting.

SECTION II.—DESCRIPTION OF SPHERE OF WORK, EQUIPMENT, SAMPLES, &c.

From the known irregularity of the occurrence of “peeling” in works practice, and in view of the divergent and sometimes conflicting opinions expressed on the phenomenon, it was obvious, at the outset, that the investigations would have to cover a wide field. The possible controlling influences appeared to be capable of classification, under the following main headings:

1. Chemical Composition of the Cast Iron.
2. Structure of the Cast Iron.
3. Temperature of Annealing.
4. Time of Annealing.
5. Rate of Heating to Annealing Temperature.
6. Nature of the Annealing Ore.

¹ *Proceedings of the Institute of British Foundrymen*, 1920-21, p. 222.

² *Ibid.*, 1922-23, p. 725.

³ *Foundry Trade Journal*, April 3 and 10, 1924.

The experimental work was therefore developed to investigate the above-mentioned influences under known conditions, as mentioned in the introduction, but at the same time every endeavour was made to make the known conditions such that they could be directly comparable with works practice.

Annealing Furnace.—Fig. 1 shows a diagrammatic sketch of a section through the annealing furnace, which was a horizontal electric resistance tube furnace, the silica tube being $4\frac{3}{4}$ inches inside diameter and 18 inches long. The tube was closed at each end with firebrick non-heated plugs 2 inches thick.

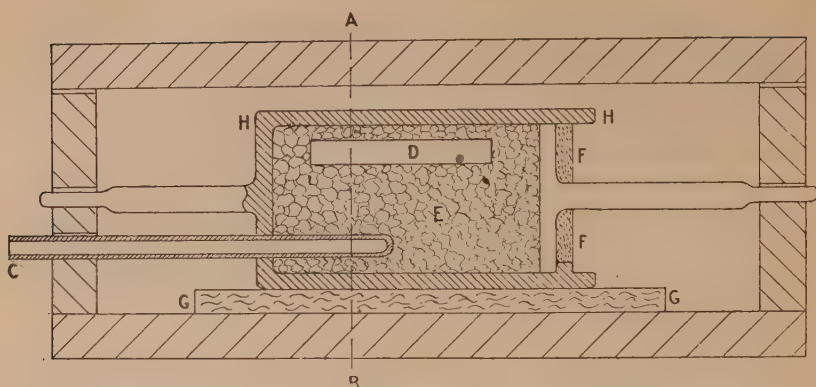
Annealing Cans.—These were made of ordinary white cast iron of the kind known in the trade as “can metal.” Each can was of cylindrical form, having an inside diameter of 4 inches and a length of 6 inches. As shown in Fig. 1, a lug was cast on one end of each box and also on the lid to help to support the box in the furnace. A hole was also cast at the end of each box, at a radius to which the specimens were inserted, to take a nickel-chromium tube containing the thermocouple. This tube was wedged into position with asbestos paper, and the sealing of the iron with each experiment was quite sufficient to seal it in. After the lid was placed in position, it was luted up with fireclay.

Specimens.—All the specimens were cast in greensand under works conditions to dimensions $3\frac{1}{2}$ inches by $\frac{3}{8}$ inch square. Bars Nos. 1, 2, 4, 5, 6, and 7 were cast from a crucible, each being from a different brand of pig iron. Nos. 3 and 8 are ordinary cupola-melted cast iron for malleable work, containing 25 per cent. of each of two pig irons and 50 per cent. of foundry scrap. Series A to E, F to H, and L to P, were each made by melting virgin pig iron and adding iron sulphide in varying amounts to give a steady increase in sulphur. CM is a metal used for annealing cans for malleable work.

The analyses of the specimens used are given in Table I., some figures being omitted in series cast from the same melt.

Annealing Ore.—This was taken from the stock in use at the malleable annealing ovens, and consisted of four parts of used ore and one part of new red hæmatite ore, the whole being of 70 Kibble mesh.

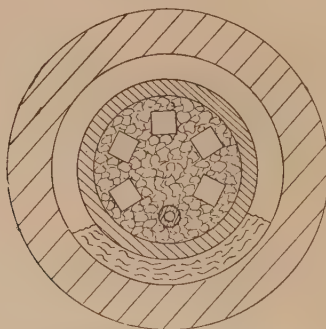
Temperature Measurements.—These were made by means of a platinum, platinum-rhodium couple inserted into the couple tube.



C = Couple tube.
F = Fireclay lining.

D = Specimen.
G = Asbestos pad.

E = Ore.
H = Experimental pot.



Section on A—B.

FIG. 1.

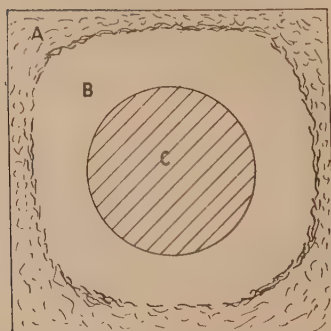


FIG. 2.

A = Oxide penetration.

B = Ferrite.

C = Pearlite and ferrite.

As no continuous recording instruments were available, the temperature records were made from frequent readings. It was found by observation that the fluctuations (due to variations in

TABLE I.

Descriptive Mark of Specimen.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Total Carbon.	Graphitic Carbon.
1	0.427	0.56	0.035	0.09	2.90	nil
2	0.635	0.35	0.046	0.099	2.95	"
3	0.496	0.53	0.060	0.075	2.75	"
4	0.718	0.30	0.035	0.130	3.15	"
5	0.750	0.178	0.033	0.225	2.88	"
6	0.875	0.42	0.040	0.020	2.87	"
7	0.690	0.068	0.070	0.025	3.07	"
8	0.760	0.345	0.079	0.20	3.30	"
A	0.605	0.278	0.043	0.24	3.49	"
B	0.575	0.375	...	0.23	...	"
C	0.555	0.406	...	0.20	...	"
D	0.585	0.425	...	0.20	...	"
E	0.590	0.405	0.043	0.20	3.46	"
F	0.575	0.110	0.085	0.08	2.96	"
H	0.605	0.140	0.083	0.12	3.10	"
K	0.560	0.200	...	...	...	"
L	0.550	0.046	0.086	0.140	3.48	"
M	0.520	0.138	...	0.158	...	"
N	0.520	0.210	...	0.138	...	"
P	0.520	0.083	...	0.164	...	"
CM	0.320	0.242	0.098	1.250	3.31	"

the electric supply) did not amount to more than plus or minus 12° C., which was well within works practice.

Rate of Heating.—To conform to works practice, the rate of heating, *unless otherwise specified*, was in each case about thirty hours to reach the required temperature, and about thirty hours to cool off.

Peeling.—For descriptive purposes, the amounts of peeling obtained have been divided into three categories—slight, moderate, and heavy. By "slight" is meant a thin flake with a thickness of the order of a piece of paper. "Moderate" is about half-way between the thickness of "slight" and that of "heavy," the latter being approximately $\frac{1}{16}$ th of an inch. These sizes are merely intended to convey a rough idea, as, naturally, many variations of thicknesses were obtained.

Testing.—To test for “peeling,” the specimens were clamped firmly in a vice for 1 inch of their length, and then gradually bent over with blows from a hammer until fracture occurred. The fractures were then examined for the separation of peel from core.

SECTION III.—DESCRIPTION OF EXPERIMENTS.

Experiment A.—To Investigate Chemical Composition.

Specimens of 1, 2, 3, 4, 5, 6, and 7, giving a wide range of composition, were packed in a box and annealed for four days (96 hours) at a temperature of 950° C.

The following were the results when tested for peeling :

A1.	A2.	A3.	A4.	A5.	A6.	A7.
None	Heavy	Slight	Slight	Slight	Heavy	None

All the samples were fully annealed, without any signs of hardness.

From the analyses it was seen that peeling was obtained with metal which exhibited no particular feature with regard to any one of its constituents. The specimen (A2) which had peeled most had quite an average analysis (Fig. 3). It was therefore decided to take sulphur prints of the specimens (longitudinal sections) and to examine them microscopically; at the same time, in view of the possible effect of “original structure,” it was decided to investigate the microstructure of specimens in the “as cast” condition.

Microstructures of Specimens 1, 2, 3, 4, 5, 6, and 7 in the Cast Condition.—All specimens showed the normal structure of white iron without any particular feature, as shown in Fig. 4 (Plate XXXI.) which is characteristic of all the samples.

Longitudinal Sulphur Prints of Specimens A1, A2, A3, A4, A5, A6, and A7.—These prints showed that the peel, where it occurred, was comparatively free from sulphur; but sulphur segregation was found at the boundary between peel and core in patches in specimens A2, A3, A5, and A7, and completely in specimens A4 and A6.

Microstructures of Specimens A1, A2, A3, A4, A5, A6, and A7.—It was found that, broadly speaking, all specimens exhibited one general type of structure. As this type of structure was also

found in all subsequent specimens which were microscopically investigated, and as it revealed the nature of the "peel," it was thought that a somewhat detailed description of it would not be out of place.

A diagrammatic sketch of the structure is given in Fig. 2, which represents a cross-section of a specimen. It is seen that the structure resolves itself into three main zones which, taken in order from the outside of the specimen to the centre, are composed as follows :

Zone 1.—Highly oxidised metal containing free globules of oxide.

Zone 2.—Ferrite becoming more and more oxidised towards the border of Zone 1.

Zone 3.—Pearlite and ferrite.

The three zones are clearly seen in Fig. 5 (Plate XXXI.), taken from specimen A2.

Zone 1.—This is the zone which forms the "peel" in a specimen. The extent and amount of peel is determined by the degree of penetration of this zone. At the boundary of this zone with the ferrite (Zone 2) it was generally found that there was an accumulation of inclusion which was more or less continuous, and the boundary formed the cleavage plane along which the "peel" (Zone 1) separated from the "core" (Zones 2 and 3). Sometimes it was found that Zone 1 contained two or more of these accumulation boundaries, in which case the specimen would exhibit a number of "peels" corresponding with the number of boundaries. The cross-sectional specimen in Fig. 3 shows one such case. Fracture taking place along two such boundaries is shown in Fig. 6 (Plate XXXI.), which is taken from a longitudinal micro-specimen (Specimen G4). Freedom from peeling was found to be consistent with either absence of Zone 1 or its presence to a very limited and irregular extent.

Zone 2.—This zone calls for very little comment. Its oxidised condition towards the boundary of Zone 1 is shown by the staining of the etching reagent in Fig. 5. As would be expected, the grain-size of the ferrite was larger the higher the temperature of annealing.

Zone 3.—The extent of the whole zone and the relative proportion of pearlite in it varied, according to the decarburisation. Generally, as might be inferred, the amount of carbon varied from a minimum at the border of Zone 2 to a maximum at the centre of the specimen. In the cases of incomplete annealing free cementite was found in the central portions.

The relative widths and extents of the three zones were found to vary considerably, according to annealing conditions.

*Experiments B and C.—To Investigate the Influence of
Temperature of Annealing.*

Experiment B.—Four days (96 hours) at 910° C. Specimens 1, 2, 3, 4, 5, 6, and 7. The results with regard to peeling were as follows :

B1.	B2.	B3.	B4.	B5.	B6.	B7.
None	None	None	None	Slight	Slight	None

The lower temperature obviously did not promote the production of peel, but, on the other hand, the specimens were not thoroughly annealed. Specimens B1 and B3 had centres which were appreciably hard when cut through with a hack-saw.

The microstructures revealed the general type of structure, in which Zone 1 was practically absent or irregular, and in Zone 3 there were areas containing more or less free cementite.

Experiment C.—Four days (96 hours) at 1010° C. Specimens 1, 2, 3, 4, 5, 6, and 7. The following were the peeling results :

C1.	C2.	C3.	C4.	C5.	C6.	C7.
None	Slight	None	Slight	Slight	Slight	Slight

The temperature of this experiment is probably above the maximum aimed at in good works practice, where 1000° C. is generally looked upon as too high. The results indicate that a high temperature tends to suppress rather than accelerate the production of peel.

All the specimens were quite soft, and the microstructures revealed the general structure, with usually a rather indefinite Zone 1, a fairly wide Zone 2, and a relatively small Zone 3, with low average carbon content, containing in some cases small amounts of graphitic carbon.



FIG. 3.

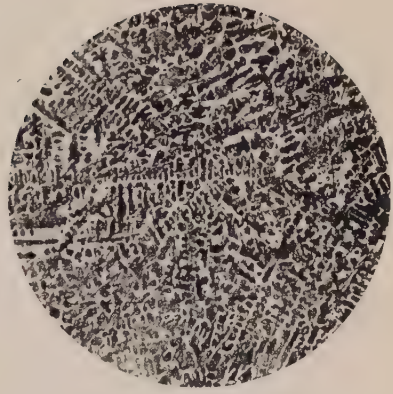
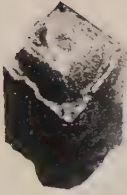


FIG. 4.— $\times 50$.
Cast structure of specimen 2.

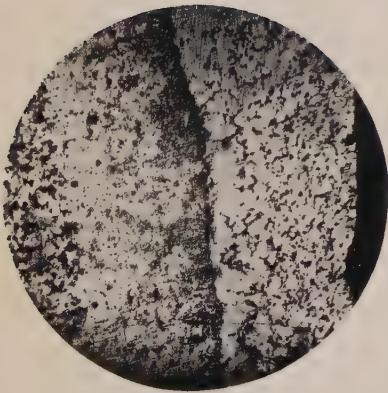


FIG. 5.— $\times 50$.

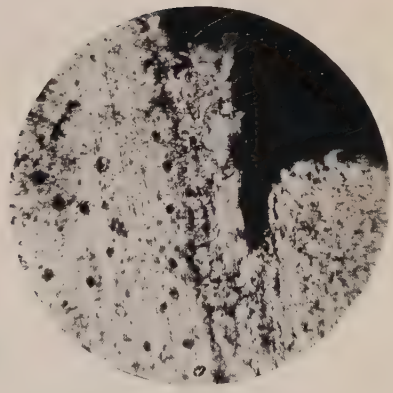


FIG. 6.— $\times 25$.

NOTE.—Figs. 4 to 6 have been slightly reduced.

Experiments D and E.—To Investigate the Influence of Time of Annealing.

As most peeling had been obtained at 950° C., it was determined to prolong the time of annealing at that temperature.

Experiment D.—Six days (144 hours) at 950° C. Specimens 1, 2, 3, 4, 5, 6, and 7. The following were the results obtained in regard to peeling :

D1.	D2.	D3.	D4.	D5.	D6.	D7.
Very heavy	Very heavy	Very heavy	Heavy	Heavy	Moderate	None

The results show at once that, under suitable conditions, the growth of peel progresses with time.

Experiment E.—As the results, especially in D1, D2, and D3, were so much more pronounced than anything obtained previously, it was thought desirable to repeat the conditions. This was done in Experiment E, which, with small variations, entirely confirmed the results of Experiment D.

The microstructures were of the general type, giving on an average a comparatively large Zone 1 and a small Zone 3.

TABLE II.

Specimen.	Silicon.			Sulphur.		
	Outside.	Second Position.	Centre.	Outside.	Second Position.	Centre.
E1	0.378	0.360	0.377	0.218	0.48	0.520
E2	0.575	0.638	0.600	0.161	0.392	0.60
E3	0.550	0.518	0.540	0.084	0.535	0.79
E4	0.745	0.745	0.770	0.127	0.351	0.64
D5	0.74	0.74	0.755	0.139	0.198	0.172
D6	0.865	0.865	0.820	0.298	0.378	0.426
E6	0.90	0.795	0.80	0.128	0.530	0.70
E7	0.750	0.750	0.71	0.066	0.061	0.061

The authors were yet without evidence as to the influence, or influences, which start the peeling phenomenon. As, in the last two experiments, the extent of the peel reached in some cases to nearly half-way between the outside and centre of the specimens, it was resolved to make analyses with regard to silicon and sulphur on sections of some of the specimens, obtained by milling off

successively one-third of the whole specimen all round. The results obtained are shown in Table II.

These figures confirm the results of the sulphur prints to the extent of revealing a minimum sulphur content in the peel.

Similar analyses on reduced sections of the bars in the hard state showed that the silicon and sulphur in the original metal are equally distributed within macroscopic limits, and without segregation.

Experiment F.—Under Works Conditions.

One of the experimental cans charged with Specimens 1, 2, 3, 4, 5, 6, and 7 was annealed on the top of a pile of cans in a works heat for six days. From the appearance of the specimens the conditions had been closely akin to Experiment C, and the results obtained were very similar.

Experiments G and H.—With Regard to the Sulphur Content of the Metal.

The variations of sulphur distribution as revealed in Table II. pointed to the possible influence of sulphur content with regard to peeling. It was therefore determined to investigate specifically the effect of sulphur.

Experiment G.—Five days (120 hours) at 950° C. Specimens A, B, C, D, F, H, K, 8, and CM. The results obtained in regard to peeling were as follows :

GA.	GB.	GC.	GD.	GF.	GH.	GK.	G8.	CM.
Slight	Slight	Slight	Slight	None	None	None	Slight	None

Unfortunately the furnace broke down twice during the running of this experiment, and at one period it accidentally reached a temperature of 1000° C. for a short time, so that a further test was made. This was the only experiment in which the high manganese bar CM was included, and in view of the reference on p. 269, it may be noted that this metal did not peel.

Experiment H.—Six days (144 hours) at 950° C. Specimens A, B, C, D, L, M, N. and P. The following were the results in regard to peeling :

HA.	HB.	HC.	HD.	HL.	HM.	HN.	HP.
Slight	Slight	Moderate	None	None	None	Moderate	None

From a consideration of these results together with former ones, it would appear that both high and low sulphur contents are deterrents towards peeling which may most easily be produced within a range of sulphur content from approximately 0.2 per cent. to 0.4 per cent. The results would also indicate that the higher the silicon content, the greater is the tendency for the production of peel.

Experiment J.—Investigating Rate of Heating.

For this experiment an abnormal rate of heating was employed to give an extreme result. A temperature of 950° C. was reached in seven hours and maintained for six days (144 hours). Specimens 1, 2, 3, 5, 6, B, D, and N. The following were the results in regard to peeling :

J1.	J2.	J3.	J5.	J6.	JB.	JD.	JN.
Very slight	Very heavy	Very heavy	Moderate	Very heavy	Heavy	Heavy	Very slight

It was obvious that rapid heating was an important factor towards the production of peel.

Experiment K.—To determine whether the Phenomenon of Peeling begins with the Annealing Effect or is Developed Later.

Rapid heating in seven hours to 950° C. and maintained at that temperature for two days (48 hours). Specimens 1, 2, 3, 6, and N. The following were the results in regard to peeling :

K1.	K2.	K3.	K6.	KN.
Very slight	Moderate	Moderate	Moderate	Very slight

The results showed that the phenomenon of peeling, when present, commences with the annealing effect.

The microstructures were consistent with the general type of structure, according to the conditions, and showed free cementite in Zone 3.

Experiments L, M, and N.—Works Conditions.

To verify the experimental results obtained it was decided to carry out a test under ordinary works conditions. An oven running an ordinary works heat was arranged as follows :

Experiment M.—A thin works can on the top of a tier in the centre of the oven, without the corresponding cans each side of it on the neighbouring tiers, so as to expose it freely to the flame.

Experiment N.—A new can in a corresponding position in the oven, but with cans each side giving quite normal conditions.

Experiment L.—Experimental can on the top of can M. Very exposed condition. Specimens in each case 1, 2, 3, 4, 5, 6, and 7.

The oven was fired more rapidly than usual, so that can N reached its normal temperature of probably 950° to 975° C. at a slightly quicker rate. Can M would also be heated at a somewhat faster rate. By intermittent temperature determinations with Watkin's patent heat-recorders, which indicated the temperature within a range of 15° C., the temperature was found to vary between 970° C. and 1000° C. Can L would be heated most rapidly, and probably had a temperature somewhat over 1000° C. The heat lasted for six days (144 hours). The results are given in Table III.

TABLE III.—*Amount of Peeling.*

Specimen.	Experiment L.	Experiment M.	Experiment N.
1	Heavy	Heavy	Heavy
2	Slight	Slight	"
3	Heavy	Heavy	"
4	Very slight	Slight	Very slight
5	"	Very slight	"
6	"	"	Moderate
7	"	"	Very slight

Experiments L, M, and N confirm the conclusion that increased rate of heating promotes the development of peel, but that a high annealing temperature retards its growth. To confirm this deduction under drastic conditions the following experiment was carried out :

Experiment P.—Heating to 1050° C. in Six Hours, Cooling to 1020° C. and maintaining for Two Days (48 Hours).

Specimens 1, 2, 3, 4, 5, 6, 7, and N.

The following were the results in regard to peeling :

P1.	P2.	P3.	P4.	P5.	P6.	P7.	PN.
Very slight	Slight	Slight	Very slight	Very slight	Moderate	None	None

The results confirm the previous deductions.

As all the above experiments were conducted with ore of normal composition, it was thought to be unnecessary to carry out experiments with regard to variations in the composition of the ore.

SECTION IV.—SUMMARY OF RESULTS.

The authors desire clearly to point out that the following conclusions are put forward in a broad and general way. At the same time they feel that the work which has been outlined has laid a foundation with regard to the influences underlying the production of "peeling in white-heart malleable," so that detailed conditions may be developed by subsequent research.

In the light of the above statement, the influences effecting the production of peel may be summarised as follows :

1. *Chemical Composition*.—Metal containing sulphur between approximately 0.20 and 0.40 per cent. will be liable to peeling, and the higher the silicon content the greater will be the liability.

2. Temperatures in the neighbourhood of 950° C. are most conducive to peeling. Higher and lower temperatures, though they do not necessarily prevent the formation of peel, retard its growth. With lower temperatures there is, of course, the risk of the material not being completely malleabilised, and with higher temperatures the possibility of burnt metal resulting.

3. The faster the rate of heating to the annealing temperature, the greater by far is the liability to produce peeling.

4. "Peel" has been found to consist of a layer or layers of ferrite containing free oxide globules as inclusions. When this layer is once formed it will continue to grow with time, according to temperature conditions (*vide* 2).

5. The work outlined above has not given any definite proof of the mechanism causing the development of peeling. With the evidence obtained the following view is tentatively put forward.

The formation of peel is the result of oxidation of the metal. There would appear to be an approximate critical temperature between 900° C. and 940° C. above which this oxidation effect may commence. As soon as oxidation begins, the growth of the oxide layer would appear to depend on the result of a race between

rate of oxidation and rate of carbon supply by diffusion from the interior. It is for this reason that rapid heating promotes rapid peel growth, as the cementite has not time to dissolve and diffuse at a rate necessary to counteract the penetrating oxidation. The retarding effect of high temperatures will be seen to be due to the more rapid solution and diffusion of the cementite.

The authors have no explanation to offer with regard to the rôle played by the sulphur content of the material.

The authors desire to record their thanks to Messrs. John Harper & Co., Ltd., Willenhall, for the foundry and analytical facilities placed at their disposal; to the Staffordshire Education Committee for the opportunity to carry out the microscopical and experimental part of the work; and to Mr. J. W. Jones, M.Sc., for active interest.

DISCUSSION.

Professor THOMAS TURNER (Member of Council), in opening the discussion, said the authors had made a very useful contribution to the study of a technical point of considerable importance. He believed they were quite correct in stating, in their third conclusion, that the rate of heating to the annealing temperature had a great influence on peeling. That was true even if the cast iron was originally of the most suitable composition. Even with cast iron of which the sulphur content was only 0.03 per cent., if the temperature were raised too rapidly, and particularly if the temperature, after being raised rapidly was a little too high, there would be the characteristic appearance of peeling. The question was comparatively simple when starting with pure materials and when the rate and time of the annealing were known, with a given packing of oxide; but commercially impure materials had to be dealt with, and in England cast iron was very rich in sulphur. He did not know why, in Great Britain, iron containing about 0.35 per cent. of sulphur was employed, unless it was because it was the only iron on the market. It was presumably white iron made in the blast-furnace that was stated to be refined in some way. In America, iron containing much less sulphur was used, and there was no reason why in Great Britain there should not be available an iron lower in sulphur content, unless there were commercial considerations. Experiments had been made at the University of Birmingham by Mr. R. H. Smith¹ on the influence of sulphur on the mechanical properties of iron, and it had been shown that, within the ordinary limits, the mechanical properties did not appear to suffer. No doubt that was why malleable iron-founders were still content to accept iron with a high sulphur content. That, however, introduced another variable and another possibility of error. The questions as to what happened to the sulphur and what was the effect of the sulphur were interesting. A number of years ago he (Professor Turner) had shown that the presence of silicon in cast iron diminished the solubility of iron sulphide and tended to throw it out of solution.² That observation was in accordance with the suggestion of the authors that when the silicon was high the greater would be the liability to peel. Sulphur and iron formed a eutectic; iron sulphide melted at 1170° C., and the eutectic at 985° C., it contained 85 per cent. of iron sulphide and 15 per cent. of iron. Friedrich had determined the outline of this diagram in 1910; it had recently been studied again, and the results of Friedrich had been confirmed by Mr. F. H. Edwards, who worked in his (Professor Turner's) laboratory, and had contributed a paper to the Institute of Mining and Metallurgy last year. It was, therefore, pretty definitely known that there was a eutectic with about

¹ *Journal of the Iron and Steel Institute*, 1915, No. 2 p. 141.

² *Ibid.*, 1888, No. I. p. 43.

85 per cent. of iron sulphide, and melting at about 985°C . That figure was not very different from the figure which was given by the authors when they said that temperatures in the neighbourhood of 950°C . were most conducive to peeling. At that temperature he presumed that, if pressure were applied, the iron sulphide eutectic could be squeezed out in precisely the same way as Dr. Stead had shown that the iron-phosphorus eutectic could be squeezed out. Some of that iron sulphide passed out into the hæmatite ore which surrounded the material that was to be annealed. The action that took place was very obscure. In some cases, if the oxide were taken and examined, interesting results could be obtained. If it were, for instance, dissolved in hydrochloric acid there would be a considerable evolution of hydrogen and of sulphuretted hydrogen; the suggestion naturally would be that the sulphur had passed freely out of the casting and gone into the hæmatite. But that did not always occur, and when it did it certainly did not occur always to the same extent. The amount of sulphur that passed out was relatively small. There was often as much sulphur left in the malleable casting as was originally present. Sulphide of iron and oxide of iron, as Dr. Percy had shown half a century before, could exist side by side, and could be treated without any reaction taking place. At a still higher temperature—towards the melting point of iron—reaction did take place, and, of course, sulphur dioxide would be given off and a sulphurous iron would remain. It therefore appeared that the acceleration of peeling by means of sulphide of iron was due to the fact that at about the temperature where that peeling was accelerated the sulphide of iron was mobile and was more readily oxidised than the iron itself, and oxide of iron and sulphide of iron more or less in mixture would be present together and help to form the peel.

There was still a further question to be considered: What was the influence of the carbon on the sulphide of iron? The authors had spoken of the diffusion of the carbon and its effect upon the peel, which no doubt was very important. The graphite that was separated from ordinary cast iron when it was examined chemically was found to contain more or less sulphur. That led to the suggestion that there was some kind of combination between the iron sulphide and the carbon. It raised the question as to whether there was an iron-sulphide-carbon eutectic at a high temperature in the same way as there was an iron-phosphide-carbon eutectic. On that point there was no evidence, but if there were such a substance, no doubt it would have an influence on the reaction.

Dr. HATFIELD (Sheffield) said the peeling of the surface of a malleable casting was, of course, an extremely well-known phenomenon. The deductions in the paper were quite in line with the conclusions he himself had formed. He had never been really able to satisfy his mind as to the mechanism of the process, but he was satisfied of two facts: in the first place, high temperature, and in the second place, high silicon

were largely instrumental in producing peeling. Furthermore, the sulphur content was high in all the old European malleable castings, so that one would take that as almost a constant in considering the process.

He had been extremely interested in what Professor Turner had said. It should be borne in mind that there was very definite evidence, as shown by the work of Dr. Wüst and some of his own early researches, that sulphur and silicon could directly combine, forming sulphur-silicide. That fact had been well brought out by a very important experiment by Dr. Stead some twenty or thirty years ago. All that evidence was dealt with in his (Dr. Hatfield's) own book on cast iron.

He was in agreement with the authors, and thanked them very much for a very interesting research. Professor Turner had asked why it was that in Great Britain irons containing a high sulphur content were used for malleable castings. Until twenty or thirty years ago the only irons that were available in Europe were the irons which came down the blast-furnaces at certain periods and were low in silicon and high in sulphur. If the iron were low in silicon it would be high in sulphur. The malleable cast-iron manufacturer required an iron which was low in silicon, so he put up with the sulphur and learned to make his malleable castings, in spite of the fact that they had a high sulphur content; whereas in America iron with low sulphur and low silicon was procurable, and an indigenous malleable cast iron of great excellence could be produced. In Europe, and particularly in England, the same type of material was now produced. He did not think peeling would be obtained with the same ease by excessive heat and high silicon with the American black-heart as with the European iron. He did not know whether the authors had tried that experiment, but he suggested they might do so.

Professor W. CAMPBELL (Columbia University, New York) said he was greatly interested in Professor Turner's remarks. A good deal depended on the amount of manganese present. In regard to the rate of oxidation of the iron sulphide, it was known that iron containing iron sulphide when heated changed its structure in that the so-called eutectic, which was previously that of iron and iron sulphide, became a mixture of iron, iron oxide, and iron sulphide, and the higher the manganese content, the slower that change took place. In regard to the question of the effect of time and temperature on malleabilisation, he thought it would sooner or later be necessary to make experiments and continue the old work of Schenk, who determined the equilibria between the iron oxides, iron and carbon, carbon monoxide and carbon dioxide, at temperatures below malleabilisation. Some one would have to find time to determine those equilibria at the temperatures at which they commercially performed malleabilisation.

Dr. WALTER ROSENHAIN, F.R.S. (National Physical Laboratory), said he wished to utter a word of warning on the question of the various

eutectics which had been referred to rather freely. Because iron and sulphur formed a eutectic at a certain temperature, and iron and phosphorus formed another, it was therefore assumed that those corresponding eutectics would be found in a complex alloy, such as cast iron. Before they could be sure of that it was necessary to know a great deal more about the constitution of those complex systems. It took a long time to study them, but the work was in hand, and he hoped that in the course of a few years a little more would be known about them. Until more was known, it was rather dangerous to say, for instance, that the iron and sulphide eutectic, which normally melted at about 950°C ., was therefore likely to be fused at 950°C . in the alloy. Of course, as a rule, the addition of further elements tended to lower the temperatures at which such bodies melted, although such was not always the case. But all those reactions were difficult to follow, and it was necessary to be very cautious with regard to theoretical explanations of the equilibria involved. The empirical facts were, of course, interesting and very important.

With regard to the high sulphur content of cast iron, a good many of those interested in cast iron were probably aware that processes for desulphurising cast iron were now being worked, and he believed successfully, though, so far as he knew, they were not being employed for the production of malleable iron. Modern investigations were confirming Professor Turner's conclusion that the presence of sulphur did not appear to affect the mechanical properties of the iron very much. Investigators—mostly in Germany—had tried very hard to show that it did, but they had failed. If sulphur were, however, a disadvantage from a malleable point of view, it was as well to remember that there were methods of removing the sulphur quite cheaply.

Mr. H. FIELD, in reply, said the primary object of the paper was to help many of the small malleable iron founders who were to be found, especially in the Midland district. The malleable iron industry was, generally speaking, much behind the other industries in the application of any scientific methods to the processes. In the paper an attempt had been made to produce a few simple rules, easy of application and not necessitating a wide knowledge of science, in order to help some of those who were undoubtedly struggling for existence in competition with iron and steel forgings. The statement in the paper that there were no other published works had reference only to the actual phenomenon of "peeling." The authors were very much indebted to Dr. Hatfield for the assistance given by his book, which they had taken into account. He thought the difference between the sulphur content of the iron which was used for malleable work in Great Britain and that which was used in America was largely due to the fact that in Great Britain the iron was melted in a cupola, while in America it was melted in the open hearth. So long as the cupola continued in use, together with the necessity of including 50 per cent. of scrap in every charge, it would never be possible to produce a low-

sulphur iron for malleable work. Even starting with a sulphur content of about 0.15 per cent., which might be called fairly low, by the time the charge had been made up and melted in the cupola that sulphur would have risen to 0.35 or 0.4 per cent. The industry was therefore prevented from using the American black-heart process until open hearth furnaces would be installed in which the iron could be kept from contact with the fuel and the sulphur thus kept low. It could never be done while the cupola held sway for melting.

The authors were very much indebted to Professor Turner for the remarks he had made about the iron sulphide eutectic; if that work were continued and the theoretical side developed, they would certainly keep Professor Turner's remarks in mind. With regard to the mobility of sulphur, in view of the many specimens he had examined, not only in connection with the paper, but over a number of years before the work was actually started, he felt there was a considerable movement of sulphur within the specimen, not only outwards, but throughout the specimen itself. Table II. in the paper showed the amount of sulphur in various specimens after they had been annealed, and proved that sulphur moved not only outwards from the skin of the casting to the ore, but also inwards from the skin to the centre of the casting. That was on the assumption that the cast samples were homogeneous, which experiment confirmed. In an examination of hard (that was, unannealed) castings the authors had not been able to find by analysis any differences in sulphur throughout the samples, but after annealing they had found in the centre portions a sulphur content considerably higher than that of the unannealed specimen, showing that there was undoubtedly a very large movement of sulphur going on. With regard to the scope of the work, Dr. Hatfield had asked whether they had tried an iron such as was used for the black-heart process. They had not in fact tried one which was quite identical; in Table I. of the paper specimen No. 5 (containing 0.750 per cent. of silicon and 0.178 per cent. of sulphur) and No. 7 (containing 0.690 per cent. of silicon and 0.068 per cent. of sulphur) were the nearest they had used. Pig iron with a sulphur content of 0.068 per cent. was almost the lowest sulphur that could be obtained in Great Britain in irons with silicon round about 1 per cent. The authors were very much obliged to Professor Campbell, who had come so far, for joining in the discussion. Dealing with the percentage of manganese and the effect which it might have in preventing peeling or any other troubles in connection with malleable cast iron, it had to be borne in mind that any appreciable percentage of manganese very much retarded the malleabilising process. In Table I. it would be noticed that in an iron which was called "CM." the percentage of manganese had been increased to 1.250, but it was realised that such an iron could not be commercially malleabilised, and therefore that high percentage of manganese had not been continued through many of the experiments. Such an iron was used in the construction of the cans in which the process was carried out because it would not malleabilise.

Iron and Steel Institute.

SOME NOTES ON THE USE OF A DIAMOND PYRAMID FOR HARDNESS TESTING.

By R. L. SMITH AND G. E. SANDLAND (ERITH, KENT).

IN an endeavour to increase the accuracy and reliability of plastic indentation hardness tests, the authors decided to investigate the possibilities of a diamond, cut to the form of a square-based pyramid, in place of such well-known indenters as the steel ball, steel cone, &c.

This pyramid type of indenter was selected for the following chief reasons :

1. That the surface impression obtained would be extremely well defined, and being square could be measured with very great accuracy across the diagonal corners.
2. That the impressions produced would be geometrically identical, irrespective of size.
3. That the deformation of the indenter would be practically nil, owing to its enormous hardness, as compared with the hardest of steels.

This investigation has been limited by the size of the diamonds to small impressions, and consequently to loads not exceeding about 100 kilogrammes. It was found, however, that these small impressions were very satisfactory, as they were not only economical on account of the small diamonds required, but the correspondingly small loads enabled the diamonds to have a very long life.

The formula adopted for obtaining the hardness numeral is :

$$\frac{\text{Load}}{\text{Impressed area}}$$

This, of course, is identical with the well-known formula used in the Brinell test.

Experiments were carried out on a given homogeneous test-piece with a number of pyramids of different angularities, and, as might be expected, the hardness numerals varied accordingly.

It was found, however, that the hardness numerals obtained with any given pyramid were practically constant, irrespective of the load applied.

Fig. 1 shows the numerals obtained from three different

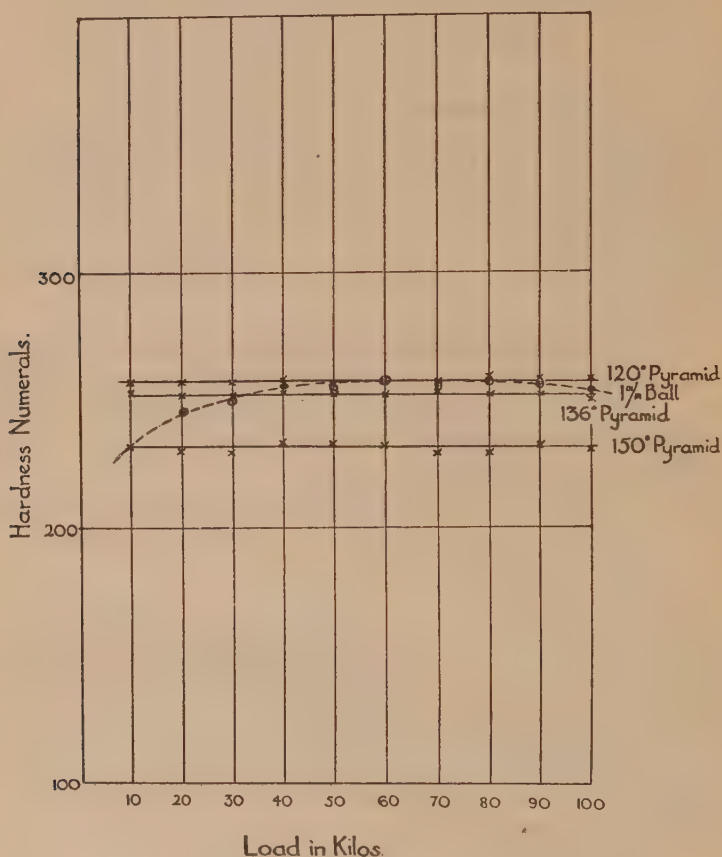


FIG. 1.

pyramids at various loads on a single test-piece of uniform hardness. (The dotted line represents hardness numerals obtained with a steel ball at various loads.)

This steadiness in the hardness numerals obtained with a given pyramid at various loads is, of course, owing to the fact

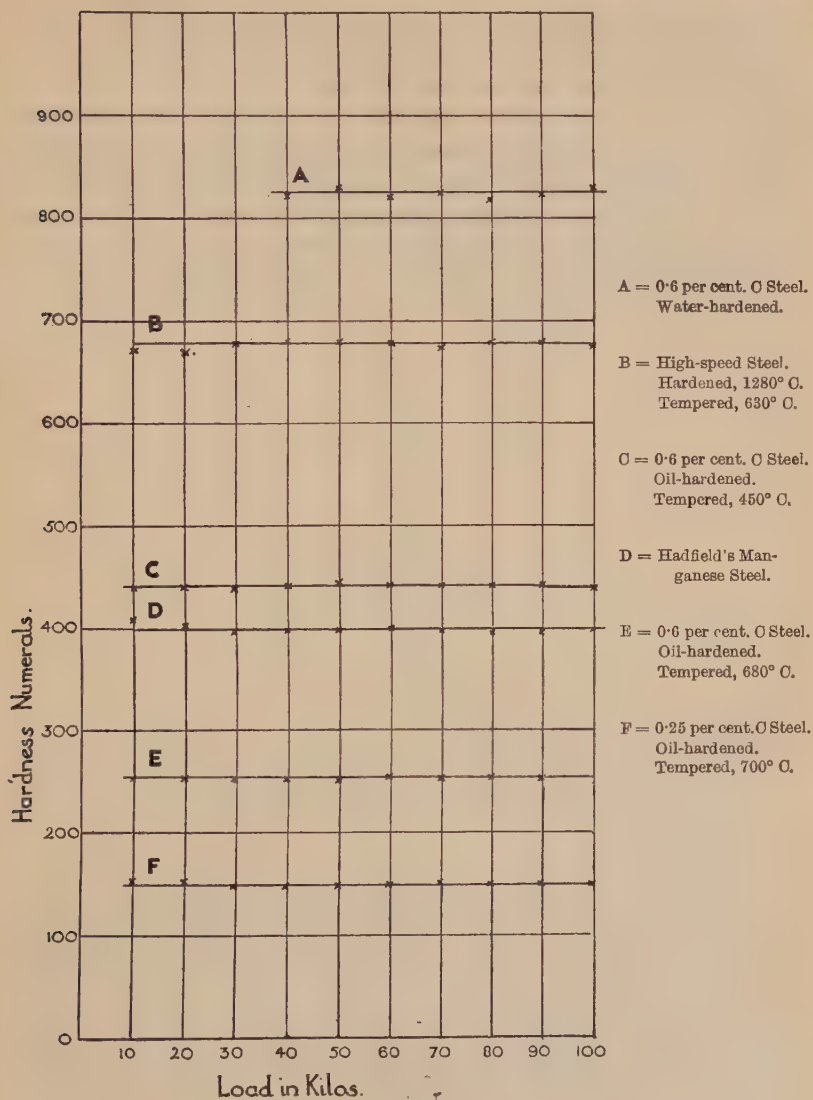


FIG. 2

that the pyramid produces impressions of geometrically similar shape, irrespective of size.

Fig. 2 shows the hardness numerals obtained with a given

pyramid at various loads on several different materials. It will be seen that even in the case of manganese steel the hardness numeral still remains steady at various loads.

Now, it is well known that the ball or Brinell test does not yield constant hardness numerals with varying loads, owing to the geometrical dissimilarity of various sized impressions. In order, however, to minimise the scope of this variation, it is generally considered advisable to restrict the diameter of the impressions to between 0.25 and 0.5 times the diameter of the ball. This, unfortunately, is sometimes hardly practicable,



FIG. 3.

although it is nevertheless very desirable in the interests of accurate and reliable testing.

It may be assumed that the ideal sized ball impression is precisely half-way between 0.25 and 0.5 times the diameter of the ball, that is, 0.375.

The tangential angle of impression corresponding with 0.375 times the diameter of the ball is 136° (see Fig. 3), and the authors, in full appreciation of the popularity of the Brinell test, have adopted as standard a pyramid of 136° across the facets. It has been found from a very large number of tests that the resulting numerals obtained are practically identical to those resulting from the ball test, when the load has been adjusted to produce an impression the diameter of which is 0.375 times the diameter of the ball.

This similarity in the hardness numerals from pyramid and ball impressions obtains, however, only in the lower regions of hardness—that is, where the steel ball does not undergo any

appreciable deformation. At approximately 525 Brinell hardness there is a very slight but definite tendency for the steel ball to yield lower readings than the diamond pyramid, and this tendency increases with increase in hardness until it becomes very pronounced indeed.

Fig. 4 has been formed from tests taken on a large number of homogeneous test-pieces covering a wide range of hardness.

These results illustrate the relationship above referred to

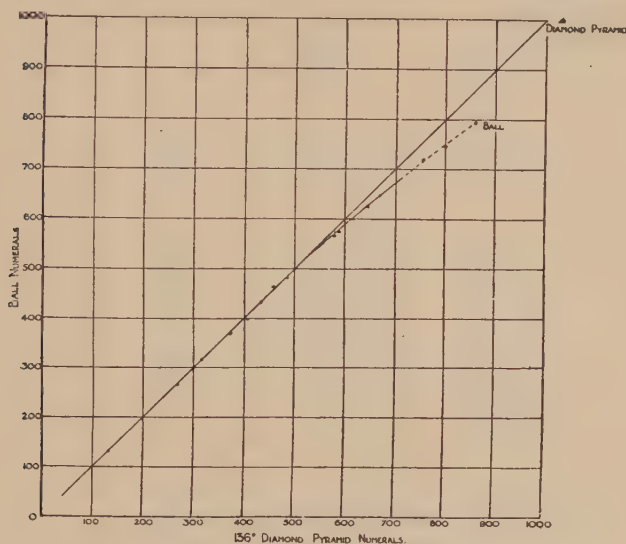


FIG. 4.

between numerals obtained with a 136° diamond pyramid and with a steel ball, when the load has been adjusted to give an impression of 0.375 times the ball diameter.

The existence of such a high degree of hardness, as indicated by the diamond numerals in Fig. 4, is definitely proved from an actual experiment, which is explained in Appendix II.

It should be noted that unavoidable variations in the hardness of different steel balls will affect the numerals obtained, particularly in the higher regions. In order to illustrate this uncertainty, the latter part of the ball curve in Fig. 4 has been shown as a dotted line.

From the foregoing experiments, it would seem that the diamond pyramid promises well and merits further investigation as an indenter in hardness testing.

The authors are indebted to Messrs. Vickers Limited for the facilities given them to carry out this investigation and also to design the special hardness testing machine ¹ with which all tests were conducted.

¹ "The Accurate Determination of the Hardness of Metals," *Engineering*, April 25, 1924.

APPENDIX I.

*Pyramidal Diamond, 136°.**Table of Conversion from Diagonal Dimensions of Impression to Brinell Hardness Numerals.*

Load, 10 kilos.

Milli- metres.	Hardness Numerals.					Milli- metres.	Hardness Numerals.				
	0.	0.002.	0.004.	0.006.	0.008.		0.	0.002.	0.004.	0.006.	0.008.
0.12	1288	1246	1206	1168	1132	0.13	1097	1064	1033	1003	974
0.14	946	920	895	870	847	0.15	824	803	782	762	743
0.16	724	707	690	673	657	0.17	642	627	613	599	585
0.18	572	560	548	536	525	0.19	514	503	493	483	473
0.20	464	455	446	437	429	0.21	421	413	405	397	390
0.22	383	376	369	363	357	0.23	351	345	339	333	327
0.24	322	317	312	307	302	0.25	297	292	287	282	278
0.26	274	270	266	262	258	0.27	254	250	246	243	240
0.28	237	233	230	227	224	0.29	221	218	215	212	209
0.30	206	203	200	197	195	0.31	193	190	187	185	183
0.32	181	179	177	174	172	0.33	170	168	166	164	162
0.34	160	158	157	155	153	0.35	151	150	148	146	145
0.36	143	142	140	139	137	0.37	135	134	133	131	130
0.38	128	127	126	124	123	0.39	122	121	120	119	117
0.40	116	115	114	112	111	0.41	110	109	108	107	106
0.42	105	104	103	102	101	0.43	100	99.1	98.2	97.4	96.6
0.44	95.8	94.9	94.0	93.2	92.4	0.45	91.6	90.8	90.0	89.2	88.4
0.46	87.6	86.8	86.1	85.4	84.7	0.47	84.0	83.3	82.6	81.9	81.2
0.48	80.5	79.8	79.1	78.4	77.8	0.49	77.2	76.5	76.0	75.4	74.8
0.50	74.2	73.6	73.0	72.4	71.8	0.51	71.3	70.7	70.1	69.6	69.1
0.52	68.6	68.1	67.6	67.1	66.6	0.53	66.1	65.6	65.1	64.6	64.1
0.54	63.6	63.1	62.6	62.1	61.6	0.55	61.1	60.7	60.3	59.9	59.5
0.56	59.1	58.7	58.3	57.9	57.5	0.57	57.1	56.7	56.3	55.9	55.5
0.58	55.1	54.7	54.3	53.9	53.5	0.59	53.1	52.7	52.4	52.1	51.8
0.60	51.5	51.1	50.7	50.4	50.1	0.61	49.8	49.4	49.1	48.8	48.5
0.62	48.2	47.9	47.6	47.3	47.0	0.63	46.7	46.4	46.1	45.8	45.5
0.64	45.2	44.9	44.6	44.3	44.0	0.65	43.7	43.4	43.2	43.0	42.8
0.66	42.6	42.3	42.0	41.7	41.4	0.67	41.1	40.9	40.7	40.5	40.3
0.68	40.1	39.8	39.5	39.3	39.1	0.69	38.9	38.7	38.5	38.3	38.1
0.70	37.9	37.6	37.4	37.2	37.0	0.71	36.8	36.6	36.4	36.2	36.0
0.72	35.8	35.6	35.4	35.2	35.0	0.73	34.8	34.6	34.4	34.2	34.0
0.74	33.9	33.7	33.5	33.3	33.1	0.75	32.9	32.7	32.5	32.3	32.2
0.76	32.1	31.9	31.7	31.5	31.4	0.77	31.2	31.0	30.9	30.7	30.6
0.78	30.5	30.3	30.1	30.0	29.8	0.79	29.7	29.6	29.4	29.3	29.1

APPENDIX II.

EXPERIMENTAL EVIDENCE OF THE POSSIBILITY OF
OBTAINING STEEL ABOVE 900° BRINELL.

The following experiment was carried out to illustrate, in a simple and definite manner, the existence of such high degrees of hardness as those shown in Fig. 4.

A strip of plain carbon tool steel (1.5 per cent. carbon), approximately 2 millimetres thick, was locally hardened by quickly

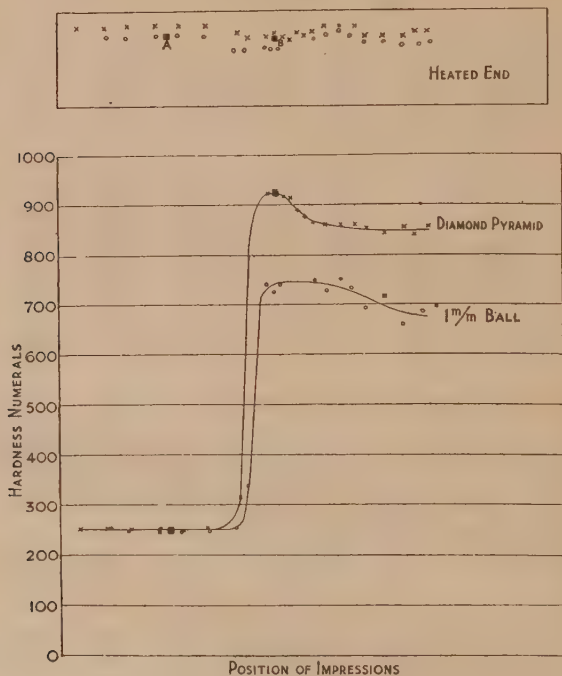


FIG. 5.

heating one end to about 1000° C. and quenching the whole piece in water. A series of hardness tests were then taken along the whole length of the strip with both the diamond pyramid and a 1 millimetre steel ball, with results as shown in the above diagram (Fig. 5).

All the values were obtained with a load of 30 kilos. At position "A," where both ball and diamond are giving identical numerals (*i.e.* 250), the diagonal dimension of the pyramidal impression was 0.472 millimetre, as may be seen from the table in Appendix I. On the assumption that the numerals as quoted in the diagram are truly proportional, the load required to produce an impression of the same size at position "B" would be :

$$\frac{925}{250} \times 30 = 111 \text{ kilos.}$$

This load was applied at "B," and the resulting impression was found to be of identical dimensions to that at "A."

APPENDIX III.

RELATION BETWEEN 136° PYRAMID NUMERALS AND 1-CENTIMETRE BALL NUMERALS AT 3000 KILOS.

Fig. 6 shows the relative hardness numerals obtained with the same test-pieces as those used in producing Fig. 4, but in this

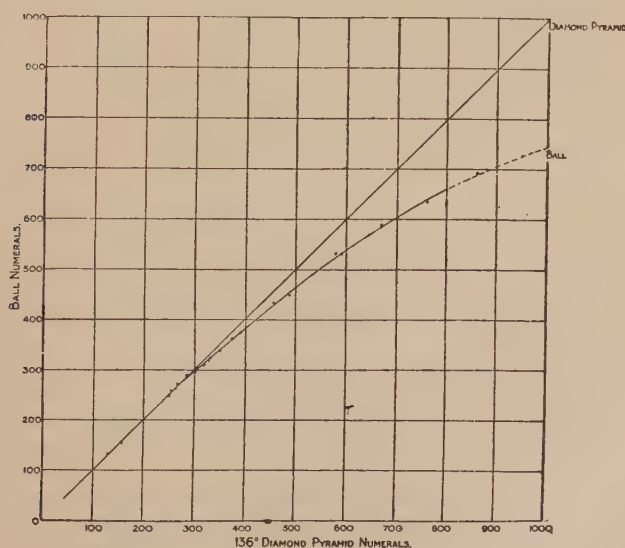


FIG. 6.

case the numerals have all been obtained at the recognised standard load of 3000 kilos with a 1-centimetre ball. Here, again, the latter part of the ball curve is shown as a dotted line to emphasise its somewhat uncertain position, owing to the inherent variation in hardness of different steel balls and the difficulty of measuring the small impression with accuracy.

As might be expected, the ball curve in Fig. 6 falls away from the diamond readings to a greater extent than is the case in Fig. 4, since with the constant load the ball impressions decrease in size with increase in hardness.

DISCUSSION.

Professor THOMAS TURNER, Member of Council, in opening the discussion, said the subject of determining hardness in very hard materials was one of great interest to the steel maker, and one which presented considerable difficulties. It had to be recognised that the differences between the grades of hardness as recorded on any of the old scales at the lower end of the series were very small. The difference between Nos. 1 and 2, or between 2 and 3 in the old Moh's scale, was very small; but when the difference between Nos. 9 and 10, approaching a hardness of, say, 500, 600, or even 900 Brinell was reached, an extended scale was involved, and it became very difficult to distinguish with accuracy in that upper region. He himself had done some work on scratch hardness testing, and had hoped to get good results in that direction. In the previous year or two endeavours had been made to correlate scratch hardness with Brinell hardness in what he might call high altitudes. The difficulty consisted in that, as the hardness increased more and more, so the width of the scratch decreased more and more, and even with very high magnifications it was not easy to be quite definite as to what the width of the scratch was. The results of those observations had been given in a paper recently communicated to the Institution of Mechanical Engineers by Mr. Shires. It was possible there might be other ways of doing it, but unless there could be some further development in the scratch hardness test, he did not see how accurate quantitative values for those very hard materials were to be obtained. That consideration led to a search for some other method, and the ordinary method was the indentation method, the well-known Brinell test. That again suffered, though perhaps not quite so much, from the same difficulty, that the harder the material to be tested the smaller was the impression that had to be observed, and the smaller the differences between the impressions. It was a question not only of microscopic measurement, but also of definition of the edge of the impression. He therefore welcomed the efforts of the authors of the paper to introduce a diamond tool of the shape of a definite pyramid and square in plan. As the authors had pointed out, the width of the diagonal and the sharpness of the corners appeared to present a greater opportunity of accuracy. He had not had an opportunity of working with the machine and, until he had actually studied it himself, he would not like to express more than a benevolent approval of the idea.

Sir ROBERT HADFIELD, Bart., F.R.S., Past-President, said he was in no way opposed to investigation or research of that kind, but he seriously thought attention ought to be paid mainly to improving the Brinell method, which was now practically the standard throughout

the world. An attempt to introduce new types of scratch by the use of the diamond pyramid was very laudable, and if the authors could help to determine extremely high hardnesses, they would be doing good service. It would be of interest, for example, to consider the case of an irresistible shell striking irresistible armour plate, the point of the shell being extremely hard and the plate being extremely hard. There would be two materials of practically the same hardness, both being 650 Brinell. That was the kind of hardness that had to be considered. If the scratch test would enable the toughness hardness, if he might use the term, to be determined as well as the absolute hardness, it would be doing great service. If two steels of exactly the same Brinell hardness, say 650, were taken, and one was treated in a special way and the other hardened in the ordinary manner, it was possible to obtain quite different results with regard to toughness. If a steel, although it had the same ball hardness, had greater toughness, it was naturally a much more valuable product. The Brinell method did not reveal or determine the toughness qualities of hard material; nor, as he understood, did the authors' method, excellent as it seemed to be. He was sure members would all appreciate the trouble which had been expended in preparing the paper. Some of those present might not be aware of the important fact that the British Engineering Standards Association had a committee now sitting to standardise hardness numbers, entirely with reference to the Brinell system. He suggested that the authors ought to get in touch with that committee, which might like to have the information now presented brought before them. The committee was trying to standardise the expressions and data used to indicate hardness, as it was thought that great service to industry generally would be rendered if standard numbers could be made available throughout the world. At present there was considerable uncertainty. Any method which would lead to uniformity would be of the greatest possible value.

He did not want anything he had said to lead the authors to think he was not heartily in sympathy with these research efforts, but he believed it would be better to pay more attention if possible to indicating the higher hardnesses by the Brinell hardness numbers which were used throughout the world. He was afraid it was rather late in the day to try to establish scratch-method tests, regarding which methods no one had done better work than Professor Turner.

Mr. HUGH O'NEILL (Manchester University) said his experience with the system of hardness testing devised by the authors was that it was a very sound system, and that their machine was the most comfortable hardness testing machine which he had tried. He believed that it really gave Brinell results even on very hard materials. The hardness numbers obtained were independent of the load (as shown by the authors in Fig. 2), except, in his (the speaker's) experience, with the softer metals. For instance, a steel which at 10 kilos load gave a Brinell number of 174,

when tested with loads up to 100 kilos had decreased progressively with load to a Brinell number of 140 ; whilst a piece of hot-rolled copper, which at 10 kilos gave a Brinell number, using the diamond pyramid, of 67, decreased to 59 at 100 kilos. It was only in the lower ranges of hardness that one found that decrease in the hardness number ; higher up it appeared to be constant. A similar decrease with higher loads—even though geometrically similar impressions were also made—had been noticed by Professor Haigh in some of his “ prism ” tests.

Professor Haigh's method gave geometrically similar impressions with different loads, but nevertheless, with the softer materials, there was a decrease in the “ prism hardness ” number. The question of the rate of loading should be studied and the time during which the load was applied. In the tests which he (Mr. O'Neill) had made the load had been maintained for not less than two minutes. The machine which the authors had devised ordinarily applied the load fairly quickly, but provision was made for adjusting the rate of application. When one came to test cold-worked materials a difficulty arose, because instead of the indentation being square on plan, the plane sides bulged outwards. That meant that the metal was piling up along the flat sides of the pyramid, for if the surface were ground down flat after the indentation had been made a square indentation remained. That meant that the cold-rolled metal was resisting outward flow. When the pyramid was driven into the surface, instead of the top metal swelling up over a considerable area, it was so resistant that it piled up along the face of the pyramid ; and, since the pyramid was sloping outwards, the effect was that of a bulge in the side of the indentation. Some sort of prescription ought to be arrived at to be used in testing cold-rolled material, because if the diagonal were measured, the hardness numbers would be high. From a diagonal measurement the area supporting the indenter was given as being smaller than that actually produced because of the omission of those supporting bulge surfaces. The test seemed to resemble Professor Haigh's “ prism ” tests, because he had noticed the same effect. It would differentiate strain-hardened material from ordinary annealed material ; when those bulges occurred it was known at once that the material had been cold-worked. He (Mr. O'Neill) had found that on very soft annealed metal, instead of getting quite square indentations, there was a tendency for the sides to be very slightly concave. The effect was not very great ; he had just noticed the tendency. In very soft material there was thus a tendency for the metal to pile up very slightly at the corners of the indentation.

Fig. 5 in the paper afforded an interesting object-lesson of the hardness of three different micro-constituents of steel. On the left-hand side of the diagram round about 250 the hardness of pearlite as measured in Brinell units was obtained. The maximum value of about 920 represented the Brinell hardness of martensite, whilst the region to the right, of about 850 Brinell, indicated a softening effect due to the adulteration of martensite with austenite.

Mr. A. HULTGREN (Gothenburg) congratulated the authors on having devised a new method and a very fine machine for carrying out hardness tests. He thought the method might be useful and convenient in testing hard materials.

The authors had chosen their scale of hardness by keeping the angle of the pyramid constant; they were very probably right in saying that by doing that they arrived at the same hardness figures as would be obtained in the ball indentation test if a constant relation were maintained between the size of ball and the size of indentation; but that was not the original definition of the Brinell test. It was a perfectly justifiable ball hardness test, but it should be kept ever in mind when using those figures that they did not represent Brinell figures as they were usually defined. Therefore the statement that Brinell hardness up to 900 had been obtained was, in his opinion, not correct. Further, there was, of course, the possibility in manufacturing a pyramid of diamond that there might be a certain variation in accuracy, whereas a ball could be made very accurately. He did not know whether that point would have any practical influence.

Professor HENRY LOUIS (Member of Council) said he quite understood the reason why the authors had chosen an angle of 136° , but he had had a certain amount of experience in such work, and he knew the difficulty of grinding the angles of a gem to that degree of accuracy. He would point out to the authors that the natural crystal of the diamond was an equi-axial octahedron. By adopting that form they would gain, from the point of view of economy, for, if they went to a diamond merchant, they could usually pick out from a parcel of uncut diamonds a few small octahedra which had not much commercial value because they did not cut very well; in that way absolutely constant angles would be obtained. Furthermore, although a diamond was hard under pressure, it was fairly easily cleaved, and the cleavage of the diamond was along those octahedral planes; so that if a diamond with the obtuse pyramid of 136° were used, it was apt to split along those planes when subject to pressure. If, on the other hand, a pyramid of the true natural angles were used, that danger did not arise, and the risk of cleavage was very much diminished; hence there were many advantages in adopting the natural octahedron of the diamond, and he would suggest to the authors that they would be well advised to work along those lines. It seemed to him to be merely a matter of simple arithmetical calculation to convert observations obtained from one form of pyramid to those obtained with pyramids of another angle. He did not think the small amount of work involved should constitute an obstacle when there appeared to be such great advantages in that method.

He wondered whether the authors or anyone else had tried using balls of sapphire. He did not mean the valuable gem sapphire, but the opaque Ceylon sapphire with which most people were familiar. Balls

made of that sapphire had been used for technical purposes ; for instance, the caps of good compass needles were made of sapphire. It was not a difficult material to work, and a very good sphere of sapphire could be obtained which, owing to its being in that imperfectly crystallised state, had not a well-marked cleavage, and therefore was not liable to fracture. It appeared to him that the use of the sapphire ball might solve all the difficulties and combine the advantages of the diamond pyramid and the Brinell methods of testing.

Mr. A. V. DE FOREST (Bridgeport, Connecticut) said a hardness-testing device had recently come into use in the United States in which the diamond indenting tool was used and was successful, especially with hard materials such as hardened tool steels. It was the Rockwell hardness tester. Instead of measuring a diameter of impression the measurement was of the depth, or, rather, the difference between a depth at 10 kilos load and a depth at 150 kilos load. The 150 kilos load was for the harder materials, and smaller loads could also be used. The depth was measured on a direct-reading dial micrometer, and there was no need to transfer the specimen from the place in which it was indented to the microscope. It was also slightly quicker to read the position of the needle than it was to read the cross-hairs on an optical micrometer. The use of the diamond was a very successful solution of the problem of the indentation tool for the higher ranges of hardness. That instrument could also be used in connection with a microscope, and the diameter of the indentation could be measured. It had not the advantage of the sharp corners, but it had the curious property which the authors had mentioned: the cold-worked materials could be distinguished under the microscope by the elliptical shape of the hole.

Dr. SAMUEL HOYT (Schenectady) referred to the selection of the particular type of indenter, and said that, in the first place, the indenter being square would enable the measurement of the width of the impression to be made very accurately. As a matter of fact, the type of machine which Mr. de Forest had described, the Rockwell, gave a reading which was very similar to that in its results, as there was little difference between measuring the depth of the impression and the diameter ; and the depth of impression with the Rockwell machine was very simply and accurately made.

Secondly, the impressions produced would be geometrically similar irrespective of size. In that respect the indenter used by the authors was similar to the Ludwik cone. That led to the fact to which Sir Robert Hadfield had drawn attention, namely, that two metals of equal Brinell hardness behaved differently ; so that he would like to call attention to the error involved in a method of testing which produced geometrically similar impressions for all loads. Professor Meyer some time ago, in his very careful and critical analysis of the Brinell ball indentation hardness test, had shown that the property of indentation

hardness was one which could not be indicated by any one figure: it was necessary to know either the entire course of the hardness curve or the empirical constants which gave at once the course of that curve. If cold-worked copper were compared with mild steel by the Brinell test, it would be found that the cold-worked copper appeared harder than the mild steel, which was not the actual case, because the copper did not scratch the steel, while the steel scratched the copper. If the hardness curves of those two materials were followed, it would be seen at once that the cold-worked copper had been robbed of its ability to harden further on deformation, whereas the steel retained that property, and for higher deformations the steel came out harder. It seemed to him that if they were to understand the conditions which Sir Robert Hadfield had mentioned they must know not only the hardness at some one empirical point, but the entire course of the hardness curve over the complete range of loads.

With reference to the deformation of the indenter, he had recently seen some 10-millimetre balls which were made of a composition which was essentially a tungsten carbide. Those balls had been tested by the Bureau of Standards in America, and had been found, he believed, to be vastly superior to the ordinary ball, in that the tungsten carbide ball did not deform when loaded to 3000 kilos by a steel which had a hardness of 700 Brinell. He had actually seen the impression himself. The impression was of exactly the same type as was obtained with the ordinary Brinell test with a much lower hardness. Tungsten carbide seemed to be an ideal material for use for the Brinell test. Inasmuch as it was desirable, as Sir Robert Hadfield had pointed out, to retain as far as possible the original Brinell test, it would seem to be desirable to make a study of the use of tungsten carbide or similar compositions for Brinell balls.

Mr. T. H. TURNER (Birmingham) thought it was a pity to introduce a test with the same angle as the Brinell, inasmuch as it might have been possible, by taking an angle of 90° , to get something more fundamental to steel-working. Mr. E. W. Fell, working under his direction, had shown that the raising of the surface at the edge of the indentation did not occur in all materials. The surface of mild steel was raised, whereas copper was driven down at the side, and with some other metals there was actually an irregular edge.

Metals had their characteristic deformations, and compression tests and tensile tests of mild steel showed that 45° was definitely a fundamental angle for that material. A compression test perhaps was most comparable with the diagram illustrated. He had not time to show the way in which the mild steel deformed under the Brinell, but the raising of the edge as shown by Fig. A (top) could be explained on the basis of the wedge theory. Since wedges of distortion did not occur in other metals, it was a reason why there was not the same raising of the surface in the other materials. Had the authors tried to make a square cone

of 45° (with faces at 45° from the normal), and was that possible with a diamond? If so, had their results given figures which were more comparable with the tensile and compression tests? The Brinell figures were very nearly comparable but not quite. He might be wrong, but he had an idea that the 45° prism would give results much more comparable with those obtained by a tensile test. Was any raising of the surface

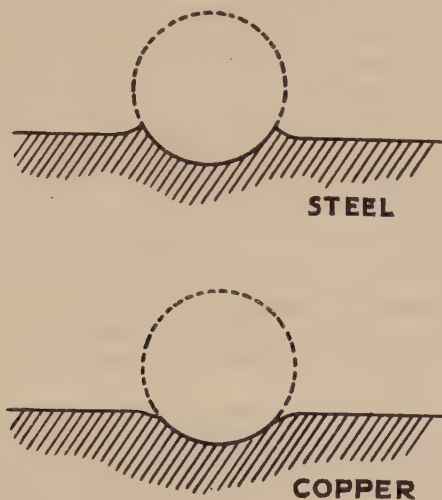


FIG. A.

noticed in that way—as he presumed it would be so with steels? Also he wished to know what degree of polish was required. Could it be assumed that no further polish was required than in the case of the ordinary Brinell test? Also what was the service life of one of the diamonds? As they must be expensive, owing to the special angle, that was an important point to those who thought of using the test.

CORRESPONDENCE.

Messrs. SMITH and SANDLAND wrote in reply that the various subjects raised in discussion were dealt with under the following headings:

1. Principle and method.
2. The use and form of the diamond.
3. The shape of impression.

1. *Principle and Method.*—With reference to Professor Turner's remarks regarding the difficulty of measuring small scratches and small

impressions obtained by the ball Brinell method, it might be of interest to note that with the standard machine employed for those tests, no difficulty was presented in measuring the diamond impressions accurately to 0.002 millimetre which on the hardest of steels amounted to an error of about 1.5 per cent.

In reply to Dr. Hoyt and Mr. Axel Hultgren, the authors felt, as Sir Robert Hadfield clearly pointed out, that there was a real need for an improvement in the ball Brinell test, which failed to give comparable results owing to the occurrence of certain variables. Moreover, the lack of uniformity in methods made it almost impossible to determine what was the usual definition, but modern practice appeared to tend towards keeping the size of impression as nearly constant as possible. In attempting to improve and standardise such tests, while bearing in mind the desirability of avoiding the introduction of a new scale, it was unquestionably advisable to remove as many sources of variation as possible, and that the authors had endeavoured to do by the use of a diamond pyramid in conjunction with a machine which ensured constant conditions of application and duration of load. From the results obtained there appeared to be every reason for assuming that the diamond pyramid numerals were identical with those which would be obtained with constant sized impressions obtained with the polished diamond ball.

Referring to the remarks made by Dr. Hoyt and Mr. de Forest concerning the Rockwell machine, the authors felt that it was not possible to compare the two methods, as they were based on entirely different principles. It was, however, somewhat surprising to note that in the case of the Rockwell machine, the shape of impression from a presumably round indenter should be elliptical when produced in cold-worked material.

In passing, it might be mentioned that with the machine used for the experiments, there was no need to remove the specimen for measurement, as the microscope was carried on the machine and swung into position over the impression.

With regard to Mr. Hugh O'Neill's remarks concerning the somewhat higher numerals obtained with the diamond pyramid at very low loads on copper and certain other soft materials, it might be stated that the authors had observed that effect and found it to be caused by the surface hardening produced in preparing the specimen for test. If the specimen were suitably etched before testing, the numerals would be found to be practically identical at both low and high loads. That very low load method of testing had been found to be quite useful in investigating certain commercial articles, the extreme surfaces of which had been variously hardened by polishing, grinding, &c. It was certainly most interesting to note that Professor Haigh¹ observed a similar effect with prism tests, but it might perhaps be mentioned that

¹ "Prism Hardness: A New Test for Hardness," *Proceedings of the Institution of Mechanical Engineers*, 1920.

he attributed that to the inadequate size of his specimens rather than to any intrinsic quality of the material.

2. *The Use and Form of the Diamond*.—The authors were in agreement with the remarks of Professor Louis concerning the value of the natural pyramidal point, and had carried out an investigation on that subject.¹ The natural points were, however, not flat-sided and seldom came to a true point, but were nearly always broken. That, combined with the difficulty of finding the axis of the natural pyramid necessitated a separate calibration for each stone. Moreover, the method of calibration while satisfactory in practice, was nevertheless open to certain theoretical objections, and the use of the natural points was therefore abandoned in favour of accurately cut stones, which were found to give identical numerals in all instances.

The pyramids referred to in the present paper were in every case cut with the natural point as a foundation, and it was found that by so doing the final pyramid could be finished to a most excellent polish. In using pyramids so cut there appeared to be no indication whatever of splitting along the cleavage planes. In the total absence of abuse, the authors were of opinion that the life of a diamond was almost indefinite. The initial cost of those diamonds was by no means excessive, and the re-cutting of a damaged stone was generally a simple matter.

In reply to Mr. Axel Hultgren it might be stated quite definitely that, although in the initial stages, the accurate cutting of the diamond presented many obstacles, after considerable experimental work those difficulties had been entirely overcome, and it was now found to be a thoroughly practicable proposition to manufacture diamond pyramids, cut and polished to a high degree of accuracy for hardness testing.

Experiments had been carried out with sapphire balls, but in addition to the disadvantage attendant upon the use of a ball, it was found that such balls crushed very easily even under light loads.

The degree of polish required was about the same as for a 1-millimetre ball test, and for accurate research work it was, of course, desirable to have a good polish on the work tested, but the polishing for ordinary routine testing presented no difficulties, emery-cloth giving a sufficiently good finish.

No experiments were made with a pyramid of an angle smaller than 120° , but it was of interest to note that in experiments with cones Mr. Hankins² observed that the smaller angles of cone were more liable to inconsistencies than were the larger, and it was reasonable to expect analogous results from pyramids. Further, more acute angles would probably be somewhat fragile and would give a considerably

¹ "An Accurate Method of Determining the Hardness of Metals, with Particular Reference to those of a High-Degree of Hardness," *Proceedings of the Institution of Mechanical Engineers*, 1922, vol. i.

² "Report on the Effects of Adhesion between the Indenting Tool and the Material in Ball and Cone Indentation Hardness Tests," *Proceedings of the Institution of Mechanical Engineers*, April 1925.

increased bulge effect. Experiments with plain carbon and nickel steels showed that the figures obtained from the diamond pyramid were more readily comparable with the tensile results than were the Brinell, a single factor being sufficient to cover the whole range. With the Brinell the factor increased with hardness.

3. *The Shape of Impression.*—The authors were most interested to have their attention drawn by Mr. Hugh O'Neill to the similarity in bulge effect between the diamond pyramid impressions and the prism impressions obtained by Professor Haigh with regard to materials which had been strain hardened. As Mr. O'Neill pointed out, on materials which were markedly capable of being further hardened by overstrain, such as annealed copper, austenitic steels, &c., an opposite effect was obtained and the sides were slightly concave; but the authors were of opinion that the cause was that the material in the neighbourhood of the sides of the impression was drawn down.¹ The authors had observed those characteristics with the diamond pyramid and found them to be useful in differentiating between those classes of material.

The steel ball, of course, produced similar results, as could be proved by sectioning an impression, but as the impression in plan was always a circle, the exact formation of the edge of the impression was not always obvious, but simply went to vitiate the definite dimensions. With the square impressions the corners were always unaffected, and it would therefore be seen that the method of taking the measurement across the diagonals gave an effect identical to a measurement of the depth of the impression from the original surface.

Iron and Steel Institute.

ON THE STRUCTURE OF QUENCHED
CARBON STEELS.¹

By B. D. ENLUND (DEGERFORS, SWEDEN).

It is a well-known fact that plain carbon steels high in carbon have a partially austenitic structure when sufficiently intensely quenched. The typical structure in such cases is shown in Fig. 1 (Plate XXXII.). Martensite needles are here embedded in a ground mass of austenite. If this steel be annealed, the martensite needles are transformed into troostite, the reaction being most marked at a temperature somewhat above 100° C. The austenite, however, does not change until the temperature is raised to about 260° C.² This is shown in the photomicrographs³ of Figs. 2 to 8 (Plates XXXII. and XXXIII.).

If the steel be of low or medium carbon content it does not present this distinct two-phase structure, even if it be quenched from a very high temperature. Figs. 9 and 10 (Plate XXXIII.) are photomicrographs of a medium and a mild steel quenched from 960° and 1100° C. The structure in this case is very indefinite, and it is impossible to discern if it be formed of more than one phase. That some of the γ -iron is preserved at ordinary temperature even in those steels may, however, be gathered from some investigations by the author dealing mainly with the change in electrical resistivity and specific volume with annealing temperature. The results thus obtained indicate also that it is not even necessary to quench mild or medium steels at an unusually high temperature to retain some untransformed austenite. When steels are quenched in the normal way, the γ - α -iron transformation is not complete. Thus *all carbon steels quenched in water in the ordinary way contain some austenite.*

¹ Abstract of an article published in Swedish in *Jernkontorets Annaler*, 1922, vol. lxxvii. p. 389.

² E. Maurer, *Metallurgie*, 1909, vol. vi. p. 47; G. Hanemann, *Stahl und Eisen*, 1912, vol. xxxii. p. 1491; *Int. Zeitschrift für Metallographie*, 1913, vol. iii. p. 127.

³ The white areas in Figs. 3 and 5 are evidently due to martensite formation after polishing. Comp. C. Benedicks, *Journal of the Iron and Steel Institute*, 1908, No. II. p. 153.

A confirmation of this result has lately been obtained by A. Westgren and G. Phragmén¹ by X-ray analysis. A steel containing 0.80 per cent. of carbon, quenched from 750° C., gave an X-ray photogram in which distinct γ -iron interferences could be seen.

EXPERIMENTAL ARRANGEMENTS.

The electrical resistance was, in the experiments carried out by the present author, measured in the ordinary way by determin-

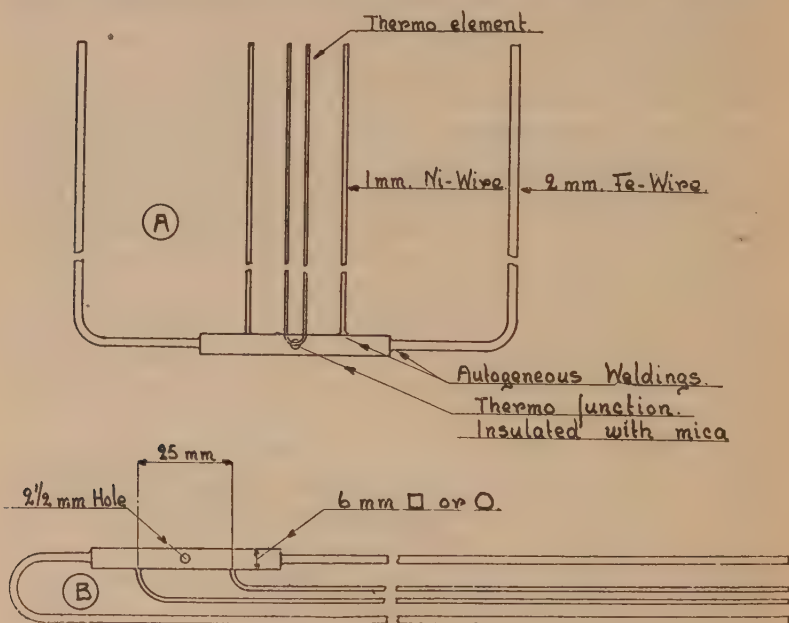


FIG. 11.

ing the decrease in voltage between two points of a cylindrical rod, through which a current was sent. The conducting wires were welded autogenously to the specimen, as shown in Fig. 11, A. Before quenching, the wires were bent together, as demonstrated in Fig. 11, B.

The quenched specimen was heated in an electrical furnace, the temperature of which could be easily regulated. The wires

¹ *Jernkontorets Annaler*, 1923, p. 463.

in the circuit for measuring the tension, being of nickel, formed a thermocouple together with the specimen, and any difference in the temperature of the two welding points would give rise to a thermo-current. By means of a millivoltmeter coupled in this circuit, it could thus be ascertained whether the specimens were uniformly heated. The temperature was measured by means of a platinum platinum-rhodium thermocouple, the junction of which was placed in a hole in the centre of the specimen.

The temperature was raised at a rate of 6°C . per minute, and

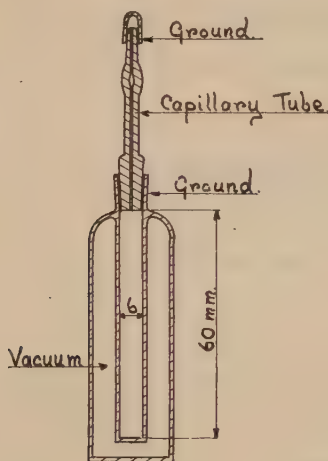


FIG. 12.

determinations of the resistance were made at intervals of 10°C . Owing to the complicated shape of the specimens, only relative values of the resistance could be derived in this way. A determination of an absolute resistance value was, however, carried out on a cylindrical rod without any holes and weldings, which had been quenched together with the other specimen made of the same steel. The value thus obtained was used as a basis for the curves representing the change of resistivity with annealing temperature. These absolute determinations were performed by means of an Enlund apparatus (Siemens and Halske, Berlin), an instrument constructed by the author for steel analysing purposes.¹

¹ A description of this apparatus is given in *Bericht des Chemikerausschusses des Vereins deutscher Eisenhüttenleute*, No. 39 (Düsseldorf, 1922); *Stahl und Eisen*, 1924, vol. xlv. p. 178.

The density measurements were carried out by means of a pycnometer, of the shape shown in Fig. 12. The values of specific volume given are means of determinations on two different specimens—cylindrical rods of 5.5 millimetres diameter and 50 to 60 millimetres length—of the same kind. Before measuring, the specimens were carefully polished.

In addition to the measurements mentioned, thermo-curves were also taken by the ordinary so-called differential method.

DISCUSSION OF THE CURVES.

The composition and electrical resistance of the investigated steels are given in Table I.

TABLE I.—*Composition and Electrical Resistance of the Steels Investigated.*

Mark.	Composition per Cent.					Specific Electric Resistance.	
	C.	Si.	Mn.	P.	S.	Annealed.	Quenched.
A	1.57	0.250	0.50	0.031	0.010	25.2	56.0
B	1.26	0.350	1.05	0.043	0.010	29.1	52.4
C	1.22	0.087	0.44	0.026	0.005	20.3	45.0
D	1.09	0.245	0.50	0.032	0.017	22.4	44.3
E	0.88	0.144	0.43	0.020	0.010	19.1	37.0
F	0.87	0.210	0.55	0.031	0.035	20.6	38.1
G	0.83	0.088	0.45	0.018	0.008	17.8	34.4
H	0.58	0.185	0.48	0.028	0.025	18.0	27.8
I	0.58	0.124	0.43	0.020	0.010	16.7	26.4
K	0.44	0.148	0.42	0.020	0.010	16.0	21.5
L	0.35	0.185	0.49	0.028	0.026	17.0	21.0
M	0.33	0.175	0.42	0.026	0.028	16.0	19.0
N	0.21	0.175	0.42	0.033	0.027	15.8	17.6

The change of resistivity with annealing temperature is shown in the curves of Fig. 13. All the curves show two bends, one appearing at a temperature of 110° to 120° C., and another at about 250° C. or 260° C., according as the carbon content of the steel is high or low. These bends are visible in all the curves, thus indicating that the same reactions occur in all the steels.

The bends of the curves consist in all cases of deviations towards the temperature axis, which indicates that a precipitation

of cementite takes place at the temperatures mentioned. As is well known, a reaction of this kind is always accompanied by an increase in electrical conductivity. In analogy with what is known to take place in high-carbon steels quenched from a high temperature, it may thus be concluded that the first break in the

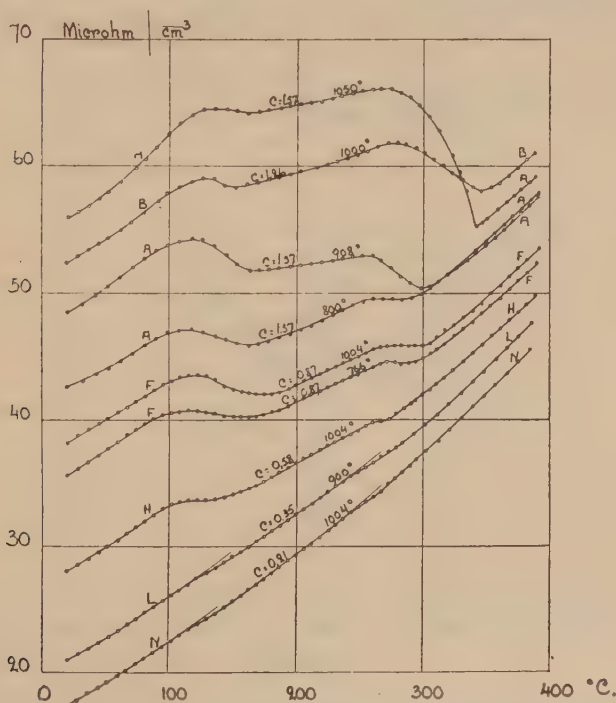


FIG. 13.

curves is caused by the transformation of martensite into troostite, and the second by the splitting up of austenite into α -iron and cementite. Though very slight, the second bend in the curves of the mild steels is quite distinct, and it is thus evident that even such steels are not free from γ -iron.

When the resistivity curves of Fig. 14 were obtained the temperature was raised very slowly, the rate being about 1° C. per minute. When possible, the temperature was kept constant for a minute or so at the reaction points, until the decrease in

resistivity was practically finished. From the shape of some of the curves it is evident that the heat liberated on the decomposition of the austenite has in some cases caused a spontaneous rise in temperature of about 10°C . The diagram of Fig. 14 fully confirms the conclusions drawn from the curves in Fig. 13.

The thermo-curves of Fig. 15 give an idea of the evolution of heat accompanying the reactions of the annealed steels. The

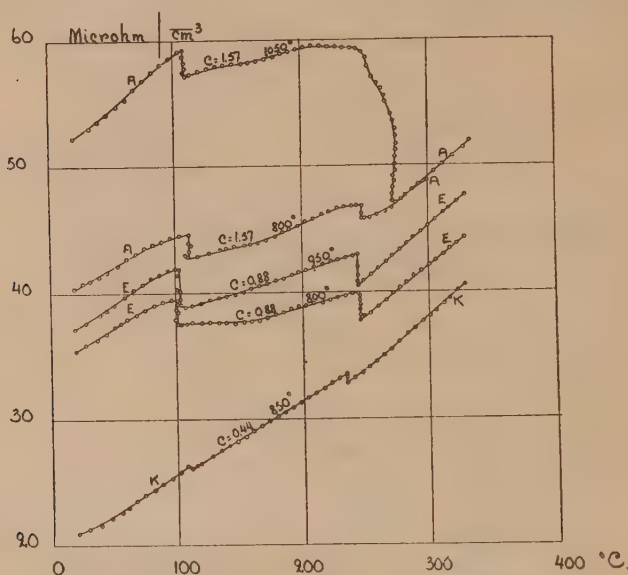


FIG. 14.

curves of steels D and H, containing 1.09 and 0.58 per cent. carbon respectively, show a break at a temperature slightly above 100°C ., which is evidently caused by the martensite-troostite transformation setting in at this temperature. This break is absent on the curve of steel M, containing 0.33 per cent. carbon, from which it may be concluded that the amount of martensite changing into troostite is very small in quenched mild steels. All the curves show, however, a distinct break at about 260°C ., which is evidently caused by the decomposition of the remaining austenite, and the break is quite distinct likewise in the curve for the steel with a low carbon content, which affords further evidence

in support of the view that these steels contain a considerable quantity of γ -iron.

The curves discussed so far give the impression that the reactions taking place in annealed steels are restricted to certain relatively narrow ranges of temperature. The resistivity diagrams seem more particularly to point in that direction. It must, however, be borne in mind that if some slowly proceeding reactions arise during annealing, they cannot be detected in the curves as long as the change of resistivity caused by the rise in temperature alone is not exactly known. The breaks in the curves correspond

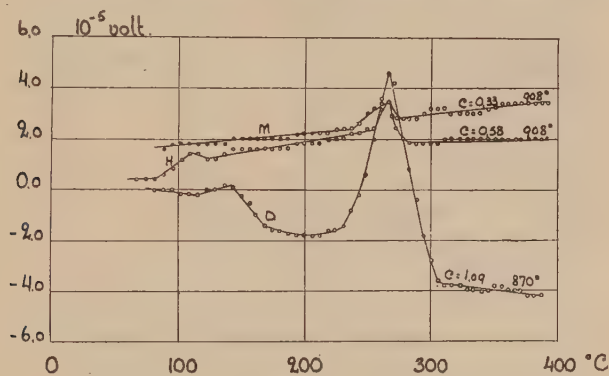


FIG. 15.

only with certain maxima of reaction velocity. To get a more exact idea of the real progress of the annealing reactions it is necessary to proceed in another way.

For that purpose the author has determined the electrical resistivity and the specific volume, at ordinary temperature, of quenched steel specimens, annealed half an hour at a series of temperatures, differing 10° to 20° C. in the range 0° to 390° C. The annealing was in this case effected in an electrical Heraeus furnace, allowing an exact regulation of the temperature within $\pm 1^{\circ}$ C. for any length of time. The steels investigated were the same as those described in Table I.

The values obtained during these measurements are given in the curves of Figs. 16 to 18. Four steels were investigated. One specimen of each was quenched at a high temperature to give a coarse-grained martensite, and another at the normal quenching

temperature in order to obtain a hardenitic structure. The pair of specimens of the hypoeutectoid steels gave practically coincident curves, which was to be expected, considering that in

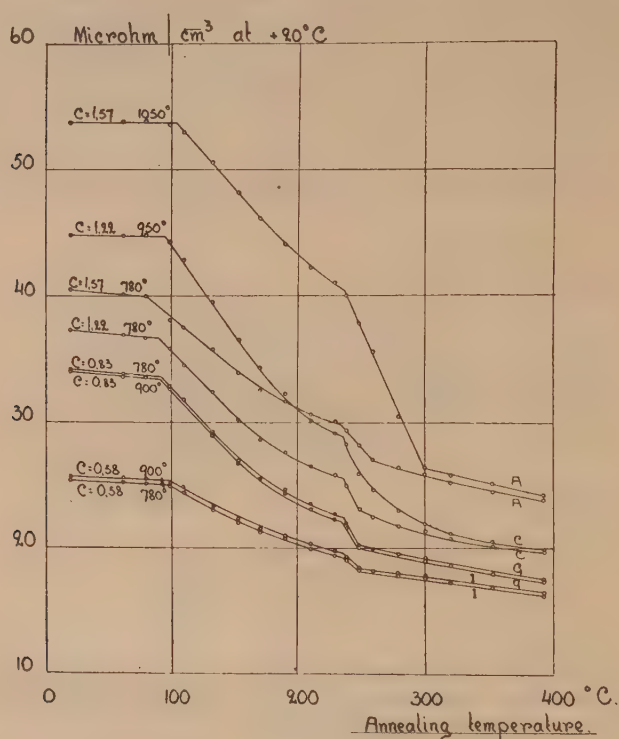


FIG. 16.

these steels the whole of the carbon is already dissolved at the normal quenching temperature.

All the resistivity curves of Fig. 16 have the same shape. At 100°C., or somewhat below this point, a rapid fall sets in, which continues, though somewhat more slowly, at higher temperatures until, at about 240°C., a new very strong fall again appears. This fall ceases at a temperature between 250° and 300°C., according as the carbon content is low or high. At still higher temperatures the curves decline very slowly.

The breaks in these curves obviously prove the existence of

the same reactions as those evidenced by the curves discussed above. The changes in the steels appearing at a somewhat lower

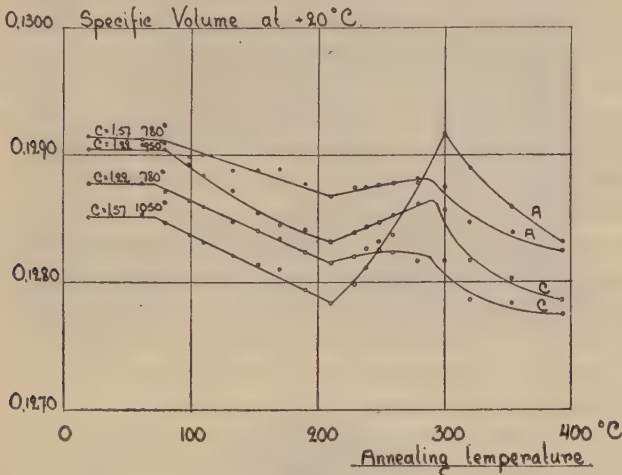


FIG. 17.

temperature in the latter experiments must be due to the longer time of annealing. It may thus be concluded from the curves

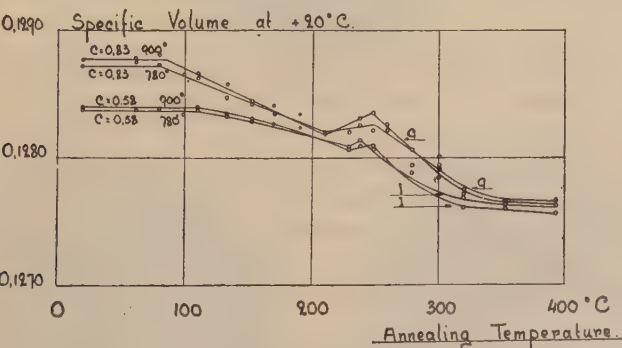


FIG. 18.

of Fig. 16 that the reaction setting in at about 100° C. is not suddenly completed, but progresses at a somewhat moderated rate at higher temperatures likewise.

The changes in specific volume with annealing temperature, illustrated in the curves of Figs. 17 and 18, agree very well with the conclusions based on the data given above. A contraction begins at a temperature somewhat below $100^{\circ}\text{C}.$, and this proceeds continuously until the annealing temperature is raised to about $210^{\circ}\text{C}.$, where a pronounced expansion sets in, reaching its maximum at 250° to $300^{\circ}\text{C}.$ The contraction is evidently caused by the formation of troostite and by the coagulation of the precipitated cementite, while the expansion corresponds with the decomposition of the remaining austenite. The first of these volume changes has been observed previously during dilatometric measurements,¹ but, as far as the present author knows, very little attention has hitherto been paid to the expansion in the range 200° to $300^{\circ}\text{C}.$ This increase in volume is nevertheless obviously a most important argument for the conclusion that there is some γ -iron preserved in all quenched carbon steels.

Collecting the results obtained, the author considers they confirm the conception that the martensite in quenched steels is transformed into troostite through annealing at 100° to $200^{\circ}\text{C}.$, while the austenite which is present in all quenched carbon steels does not decompose until it is heated to 200° to $300^{\circ}\text{C}.$

SUMMARY.

Measurements were carried out in order to determine the influence of annealing on the electrical resistivity and the specific volume of quenched carbon steels, which have confirmed the fact that the martensite is transformed into troostite at 100° to $200^{\circ}\text{C}.$, the reaction being most marked at about $110^{\circ}\text{C}.$ They also indicate that the austenite retained after quenching is decomposed at about $260^{\circ}\text{C}.$ *Even when steels are low in carbon they contain some untransformed γ -iron (austenite) after quenching.*

The author wishes, in conclusion, to express his gratitude to Mr. K. Amberg, of the N.K.A. Ball-Bearing Company, Gothenburg, for his assistance in taking the photomicrographs.

¹ G. E. Svedelius (Thesis, Upsala, 1896), *Philosophical Magazine*, 1898, vol. xlvi. p. 173; G. Charpy and L. Grenet, *Comptes Rendus*, 1903, vol. cxxxvi. p. 92; P. Chevenard, *Revue de Métallurgie*, 1917, vol. xiv. p. 610.

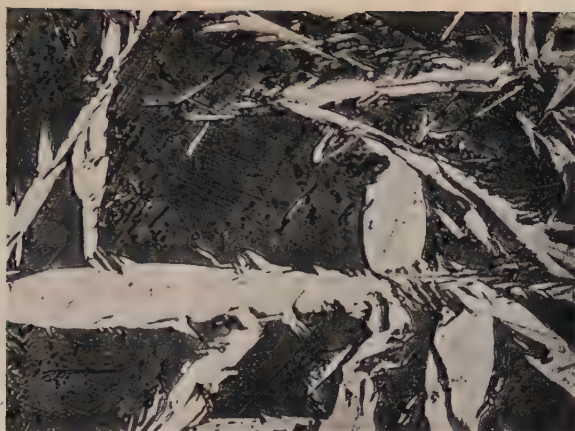


FIG. 1.—1.57 per cent. C. Quenched in water .
after 2 hours at 1100° C. $\times 1000$.



FIG. 2.—Same as in Fig. 1, annealed
at 95° C. $\times 1000$.

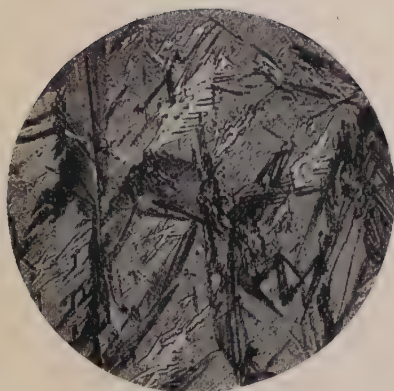


FIG. 3.—Same as in Fig. 1, annealed
at 125° C. $\times 1000$.



FIG. 4.—Same as in Fig. 1, annealed
at 150° C. $\times 1000$.

Note.—Figs. 1 to 10 have been reproduced one-half original size.

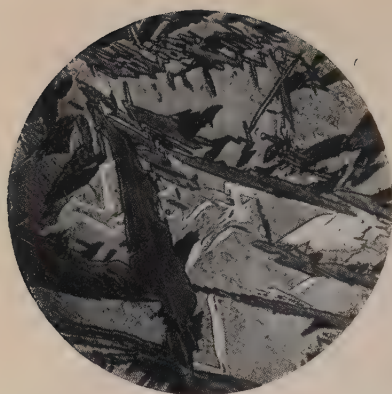


FIG. 5.—Same as in Fig. 1, annealed at 190° C. $\times 1000$.

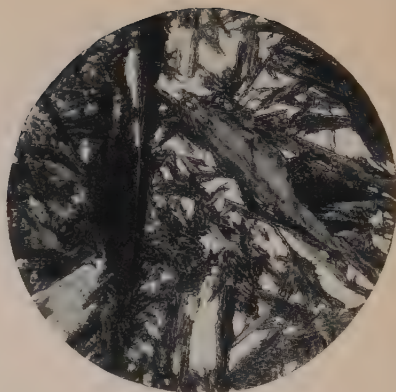


FIG. 6.—Same as in Fig. 1, annealed at 225° C. $\times 1000$.



FIG. 7.—Same as in Fig. 1, annealed at 270° C. $\times 1000$.

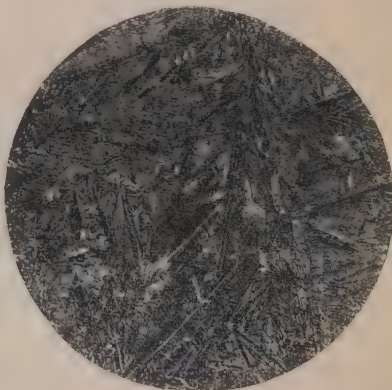


FIG. 8.—Same as in Fig. 1, annealed at 350° C. $\times 1000$.

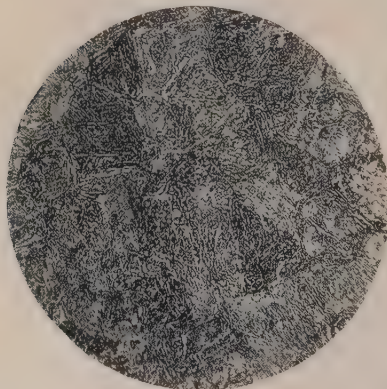


FIG. 9.—0.88 per cent. C., quenched at 960° C. $\times 250$.

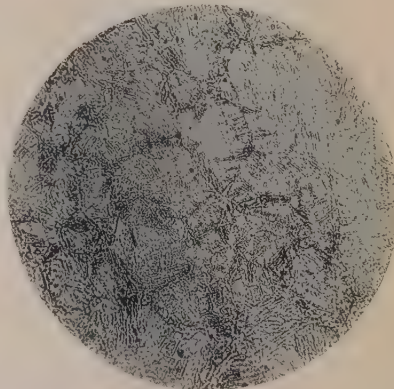


FIG. 10.—0.21 per cent. C., quenched at 1100° C. $\times 250$.

Iron and Steel Institute.

OBSERVATIONS ON MARTENSITE AND TROOSTITE.

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THE observations recorded in the following paper have been made during the course of an investigation, the aim of which was to trace the origin of the different structures grouped under the term Martensite. As the work progressed, it soon became obvious that before the results could be interpreted with any degree of confidence, the formation of troostite and its subsequent behaviour in tempering would also have to be considered. For this reason the name of the latter constituent is included in the title of the paper. The inquiry has been confined entirely to the microscopic examination of various quenched specimens, and while the facts thus derived seemed of sufficient importance to justify their presentation, it must nevertheless be admitted that much still remains obscure. On the subject of the intense hardness of martensite the research has afforded little, if any, fresh evidence; indeed, it is very doubtful whether a solution of this problem is possible by the aid of the microscope alone, and, consequently, no reference is made to the many theories on hardening. For convenience, the effects obtained are discussed under two main headings—namely, quenching effects and tempering effects. At least four types of martensite are distinguished, and it will be seen that the changes which occur in tempering lend support to this classification.

The carbon and manganese contents of the ordinary steels most often employed in the experiments are given below. Sample C is the only one requiring any comment. It consisted of a case-hardened piece of steel plate, the carbon content of which steadily diminished from about 1.50 per cent. at the surfaces to 0.20 per cent. in the central part. Frequent use was made of this sample, because it enabled structural variations over a wide range in composition to be obtained in a single section.

Analyses of Steels Used.

No.	Carbon per Cent.	Manganese per Cent.
A	0·03	0·32
B	0·19	0·52
C	0·20 to 1·50	0·47
D	0·59	0·77
E	0·78	0·75
F	1·02	0·40
G	1·39	0·40
H	2·35	0·61

In the earlier experiments, the specimens were quenched in rapidly stirred ice-brine at a temperature of about -15°C . Later,

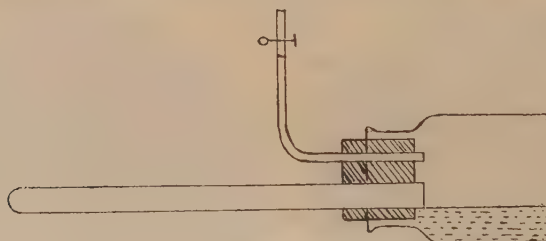


FIG. 1.—Quenching Apparatus.

this method was replaced by another in which the cooling medium was mercury. The apparatus employed was very simple and needs little explanation. It consisted of a wide-mouth 2-ounce bottle (Fig. 1), containing 15 cubic centimetres of mercury and fitted with a rubber stopper, through which passed a short silica tube and a bent piece of glass tubing. A specimen to be quenched was placed at the closed end of the silica tube, the cork tightly inserted, and the apparatus twice exhausted and filled with dry hydrogen. The end of the silica tube was then heated in a small horizontal electric furnace which had previously been raised to the required temperature and, to keep the mercury cool, the lower half of the bottle was immersed in cold water. Finally, the tube was withdrawn quickly, held in a vertical position, and the mercury rapidly shaken as the specimen fell into it. In this way, after a little practice, excellent quenchings were obtained equal to

if not better than, those given by ice-brine. The high thermal conductivity of the mercury and the absence of scale on the specimens were both of advantage. Extremely thin pieces weighing as little as 0.05 gramme could be heated and almost instantaneously quenched without any appreciable decarburisation of the metal taking place.

Throughout the investigation the following three reagents were used for developing the structures :

- (1) A 2 per cent. solution of picric acid in alcohol.
- (2) An alkaline solution of sodium picrate.
- (3) Kourbatoff's reagent, consisting of a 4 per cent. solution of nitric acid in iso-amyl alcohol.

QUENCHING EFFECTS.

1. *Types of Martensite*.—A careful examination of a large number of thoroughly quenched specimens made it clear that four types of martensite, each with distinctive characteristics, are to be found in steels of different carbon content. It will be convenient to describe these first.

Type I. is that of the well-known felted or acicular structure, and is found in steels containing up to about 0.60 per cent. of carbon. An example is seen in Fig. 20 (Plate XXXVII.). The peculiar configuration of this acicular martensite is caused by an unequal attack of the reagents along certain of the crystal planes in each grain. Occasionally a few evenly etched crystallites, sometimes in twin formation, appear as shown in Fig. 10 (Plate XXXV.). As the carbon content is increased the coarseness of the needles tends to diminish.

Type II. is found in the comparatively narrow range between about 0.60 and 0.75 per cent. of carbon. In this type the larger, clearly defined crystallites are numerous, while the acicular structure may be almost entirely absent from many of the grains. Typical illustrations are given in Figs. 8 and 13 (Plate XXXV.).

Type III. (Fig. 39, Plate XXXIX.) occurs in steels with a carbon content between approximately 0.75 and 1.60 per cent., and has been described by Portevin and Garvin as martensite-austenite.¹ It consists of lenticular plates and crystallites, similar to

¹ *Journal of the Iron and Steel Institute*, 1919, No. I. p. 469.

those of type II., embedded in a minutely pitted dark ground-mass. The crystallites sometimes have the shape of arrow-head or butterfly twins, and may be crossed by a number of parallel markings.

Type IV. (Fig. 14, Plate XXXVI.) appears in steels containing more than 1.60 per cent. of carbon, which are known to be austenitic when quenched. It was first described by Osmond, and consists of narrow elongated crystals, often present in the austenite in a zigzag arrangement. A median line frequently divides the crystal into unsymmetrical halves, and these are generally intersected by dark parallel markings resembling Neumann lines, an effect also to be observed, as remarked above, in type III.

In a quenched specimen of suitably varying carbon content, these four types pass from one to the other without any clear line of demarcation between them. Such a specimen was prepared as follows. A small cylinder of sample B was bored two-thirds of its length and tightly fitted with a core of sample H. It was then heated *in vacuo* for fifteen minutes at 1000° C. and, on removal from the furnace, quickly hammered down on the anvil to a piece $\frac{3}{16}$ inch thick. A very satisfactory weld was thus obtained. The piece was next heated at 1000° C. for forty-five minutes, which allowed the carbon to diffuse, so that it gradually increased from 0.20 at the surfaces to 2.35 per cent. in the centre. All four types of martensite were clearly to be seen in a rapidly quenched section of this composite sample. At the margins type I. was present. Then the larger crystallites distinctive of type II. began to appear. This type, in turn, was displaced by type III. with the dark minutely pitted infilling material. Still further inwards the crystallites of type III. became less numerous, until finally, when the ground-mass was unmistakably austenite, they formed the martensite of type IV. The change in the character of the ground-mass as the carbon content increased was very noticeable; while, on the other hand, the structure of the crystallites did not apparently alter to any extent. This observation strongly suggested that in each type they represent the same martensitic growth.

The size of the crystallites increased with that of the grains in which they were formed, and it therefore depends chiefly upon the temperature of heating. Moreover, repeated experiments proved that, even when specimens were heated up to the point

of incipient fusion, the type characteristic for each particular steel did not change, provided decarburisation was avoided. Confirmation of the statement made by Rawdon and Epstein in their work on martensite,¹ that the length of heating makes no difference to the structure, was also obtained.

It should be emphasised that the above types are to be found in the different steels only when these are very rapidly quenched. If, during the transformation, the critical cooling velocity for the particular type is not reached, then in higher carbon specimens a lower type of martensite will be formed. Illustrations of this were produced by removing the mercury from the apparatus (Fig. 1) and cooling small pieces of samples C and H, each about 0.5 gramme in weight, in hydrogen alone. Quenched in this way, the latter sample showed type III. martensite instead of type IV., and the former types I. and II. only, together with some troostite, in the hypereutectoid region, as seen in Fig. 4 (Plate XXXIV.). In neither steel was the type normal for the quickest cooling produced.

The results given by sample C in the foregoing experiments were particularly noteworthy in that they did not support Portevin and Garvin's statement² that the critical cooling rate is a minimum in the neighbourhood of the eutectoid composition. The martensite always steadily diminished in quantity towards the eutectoid region, being replaced by troostite, and in the hypo-eutectoid zone it was completely absent. According to the above statement, however, it should have been present in greatest quantity in the eutectoid area.

Attempts were made by means of the quenching method to prevent altogether the formation of martensite in steels normally giving types I., II., and III. For this purpose very thin pieces, weighing less than 0.05 gramme, of several samples were heated in hydrogen for a few minutes at 900° C. and then quenched in mercury with the utmost rapidity. These attempts met with no success; in fact, the structures appeared to be identical with those observed in much larger quenched specimens of the same steels. The generally accepted view that the transition cannot be

¹ "Structure of Martensitic Steels, &c.," U.S. Bureau of Standards, 1912, *Scientific Paper No. 452*.

² *Loc. cit.*

prevented when less than 1·5 per cent. of carbon is present was thus confirmed. Even when an alloying element, known to lower the transformation, was also present in appreciable quantity, the same result was still obtained. For example, very thin pieces of two 0·50 per cent. carbon steels, one containing 4·10 per cent. of nickel and the other 3·20 per cent. of manganese, gave their normal martensitic structure when similarly treated. Since, therefore, austenite could not be retained in these samples, it seems unquestionable that its complete retention in plain carbon steels is an impossibility.

2. *Surface Martensite.*—The fact that martensite appeared, as shown above, after a quench so rapid as to be almost instantaneous, raised a doubt as to whether the structure was not actually formed in the steel prior to quenching, the more so that some evidence of this had been found by Saniter¹ in high-temperature etching with fused calcium chloride. In considering this point, it was thought that the examination, after quenching, of a previously polished surface might give some useful information. Accordingly, a small prepared section of the case-hardened sample C was heated in hydrogen at 1000° C. for four minutes and quenched, the comparatively short heating being given in order to avoid the possibility of any serious decarburisation by the hydrogen.

When viewed under a medium power objective, the polished surface was seen to be covered throughout by fine needle-like markings arranged in a pattern strongly resembling the structure of type I. martensite, as shown in Fig. 11. On applying an oil immersion lens, and so placing the condenser that the field was illuminated by the margin of the cone of light, an effect similar to that shown in Fig. 3 was observed. A fine dark network revealed the positions of the grain boundaries present at the surface of the hot specimen, and each grain contained a number of V-shaped ridges, often in triangular formation. That these ridges were really in relief was proved by the fact that a light repolishing on the cloth rounded their edges.

The question as to whether this effect was due simply to the action of the hydrogen and mercury on the metal had, of course, first to be dealt with, and attempts were made, therefore, to produce it in other ways. Water-quenching in an atmosphere of

¹ *Journal of the Iron and Steel Institute*, 1897, No. II., and 1898, No. I.

hydrogen was one of the methods tried and, in order to prevent any water vapour reaching the specimen in sufficient quantity to cause tinting, a few pieces of calcium chloride were placed at the entrance of the silica tube (Fig. 1). The relief structure was obtained on several specimens treated in this manner. It was also obtained in the absence of any appreciable amount of hydrogen by mercury quenching in a vacuum. These experiments thus proved that neither hydrogen nor mercury, though convenient to use, were essential.

On examining the section of the case-hardened sample C, it was especially noteworthy that, notwithstanding the variation in the percentage of carbon across the surface, no difference could anywhere be detected in the appearance of the raised parts. This uniformity was invariably observed in all subsequent work. The character of the structure did not depend in any way upon the carbon content of the steel. It was found, however, that the presence of a little carbon in the iron was a necessary condition. For example, the structure could not be produced on polished surfaces of electrolytic iron of high purity; only the γ -iron grain boundaries were to be seen. But, when a small section of sample B was also placed in the tube at the closed end, the minute quantity of carbon transferred from one to the other by the hydrogen in four minutes at 1000°C . was sufficient to bring about the result shown in Fig. 36 (Plate XXXIX.).¹

From the appearance of these surface structures, and the fact that the presence of carbon was a necessary condition of their formation, it seemed obvious that they were the result of a martensitic growth. The following observations confirmed this conclusion.

(a) On quenched specimens of very low carbon material, such as Armco iron or sample A, the effect was only to be seen near the margins. Now, when a fresh surface was prepared by grinding away a very thin layer of the steel, it was found that the martensite was distributed within in an exactly similar way; a border of this constituent surrounded a central area of ferrite grains, as indicated in Fig. 37 (Plate XXXIX.). This correspondence

¹ It has previously been shown by the author that the transference of carbon by hydrogen from one iron to another can occur in this way (*Journal of the Iron and Steel Institute*, 1920, No. II. p. 154).

of external and internal structures could scarcely be regarded as accidental. It is remarkable that at the other end of the carbon series precisely the same thing occurred. At the margins of quenched specimens of sample H the surface effect was generally to be seen, while the middle area was usually entirely austenitic. Here, also, on preparing a fresh surface, type IV. martensite was only to be found at the edges.¹ In both cases the explanation appears to be that martensitic growth has been induced at the corners and edges by the greater stresses produced in those parts during the quench.

(b) In the foregoing experiments with sample H, additional evidence that the V-shaped ridges were simply martensite crystallites was obtained by repolishing the surface on the cloth and applying Kourbatoff's reagent. Figs. 26 and 27 (Plate XXXVII.) show an area before and after this treatment. A comparison with the zigzag martensite of Fig. 14 will give an idea of the similarity of the etching. As will be described later, the structural identity of the external crystallites with those formed within the material was revealed in a striking manner by their behaviour in tempering.

(c) When a section of the case-hardened sample C was quenched in hydrogen alone, from about 720° C., only the hypereutectoid region contained martensite; the remainder of the steel consisted of either troostite or sorbite. So also at the surface, no crystallites in relief were to be seen except on the hypereutectoid part.

While these observations plainly indicated that the effect under consideration was surface martensite, they further showed that the relief structure was not present at the temperature of quenching. If such had been the case, the formation of crystallites in (c) above would not have been confined to the hypereutectoid zone. Numerous specimens of this particular sample were quenched in mercury during the course of the investigation, and invariably the surface martensite was produced at all parts. With certain of the other samples used, however, especially those having a carbon content in the neighbourhood of the eutectoid

¹ The formation of martensite at the edges of austenitic specimens has previously been observed and discussed by Benedicks (*Journal of the Iron and Steel Institute*, 1908, No. II. p. 243).

composition, this did not always occur. Frequently on samples D and E, for example, very few crystallites appeared, and occasionally none at all. But when the specimens were quenched in mercury at 50° C. crystallites were readily produced. Here, again, it is obvious that they did not exist before quenching began. Martensite must therefore form with great rapidity at some stage in the cooling of the specimen, and the surface effect clearly corresponds to that produced on austenitic specimens when immersed in liquid air.

It may be inferred from their size and shape that the larger crystallites found in type II., and occasionally in type I. (Figs. 8, 10, and 13, Plate XXXV.), are the first to form. That is undoubtedly the case in types III. and IV., because no other kind appears, and since the observations indicated that the larger crystallites in type II. represent the same martensitic growth, the above inference appears to be correct. If this be the case, then the fine acicular crystallites must be the result of a second growth at a lower temperature. Portevin and Garvin¹ have located the temperature of martensitic formation at about 300° C., which point they designate Ar", and there can be little doubt that, where types I. and II. are produced, this point denotes the region of formation of the second growth, since by far the greater bulk of the steels is comprised of the acicular crystallites.

3. *Twinning.*—The internal structure of the surface crystallites, as revealed by etching, afforded unmistakable evidence that they are composite in character; in fact, there can be little doubt that they are the result of a repeated twinning which takes place during the transformation stage. Fig. 2 (Plate XXXIV.) shows an etched area on the hypereutectoid part of a specimen from sample C, which was covered with crystallites similar to those seen in Fig. 3. The line separating the light and dark portion of each crystallite coincides with the twinning plane, as indicated by the apex of the V-shaped ridge. This effect is strikingly similar to that observed by Carpenter and Edwards² in a twinned copper-aluminium alloy. It should be stated in passing, however, that the darker areas shown in Fig. 2 are due to the incipient formation of troostite in one part of each twin,

¹ *Loc. cit.*

² *Journal of the Iron and Steel Institute*, 1914, No. I., Plate XIV., Figs. 6 and 7.

but even when this constituent was absent the composite structure of the crystallites could still be seen.

It is, of course, well known that twinning is common in γ -iron. When it occurs, the grain appears either to be divided in two by a straight line or to contain one or more parallel bands which develop slip on straining, of the "staircase" pattern. Twinning of this kind was repeatedly noted in all quenched specimens of sample H. Instances of γ -iron twinning were also obtained, even on the surfaces of low carbon specimens, if oxygen were present in the quenching apparatus in sufficient quantity to cause tinting. Under these conditions, the exceedingly thin film of oxide formed at the temperature of heating often showed strong contrast in colour on the two halves of the twin, as illustrated in Fig. 5. In character, this twinning is quite distinct from that of the surface martensite, and when the two kinds occur together they can at once be distinguished by the fact that the latter is always in relief. It is very probable that the orientations of the twins in types III. and IV. martensite are frequently determined by the positions of the twinning planes in the γ -iron grains. Thus, in the case of type IV., the direction of crystallisation changes whenever an austenite twinning plane is reached, and this appears to explain the peculiar zigzag formation common to this type. The author is of the opinion that the martensite twinning described by Carpenter and Edwards can also be explained in this way; the orientation of the acicular structure differs in the two halves of each original γ -iron twin, producing the effect they have depicted.

4. *Structureless Martensite*.—The frequent absence of any surface crystallites on specimens of samples D and E, when quenched in cold mercury, is quite in accord with the fact that sometimes martensite can be obtained which appears to be structureless when etched with acid reagents. Such martensite is occasionally to be seen in quenched alloy steels. Bain,¹ for instance, could find no indication of a martensitic structure in austenitic chrome steels which had been temper-hardened. Several cases were encountered during the present investigation where hard martensite, devoid of any acicular structure,

¹ *Transactions of the American Society for Steel Treating*, 1924, vol. v. pp. 89-105.

had formed ; in fact, this structureless variety may almost be regarded as a fifth type. The following cases may be given :

(a) It was present together with troostite in small sections of sample G, after they had been quenched in hydrogen only. On etching, white and black structureless areas were obtained.

(b) When specimens of sample B were slowly cooled from 1000°C. to 700°C. and quenched, many of the hardenite areas embedded in the ferrite could not be etched by Kourbatoff's reagent, while the remainder showed only faint traces of type III. martensite, as illustrated in Fig. 12.

(c) An effect similar to the above was observed when specimens of a medium carbon steel, such as sample D, were rapidly cooled through the same temperature range and then quenched. Between Ar3 and Ar1 a small amount of ferrite separated from the solid solution, but equilibrium conditions were not established in the short interval of cooling. As a consequence, a concentration of carbon occurred in the γ -iron bordering the ferrite areas, and here structureless martensite was produced in quenching. Rosenhain and Haughton's ¹ reagent was found to be very useful for etching these specimens. Fig. 19 (Plate XXXVI.) shows a typical area. The ferrite crystals in the centre are surrounded by white structureless martensite and, outside the latter, dark acicular martensite is to be seen.

TEMPERING EFFECTS.

5. *Types of Troostite.*—As previously remarked, evidence of the incipient formation of troostite was to be seen in places on the etched surfaces of quenched specimens high in carbon. It was found very difficult to prevent entirely this transformation at the outside ; indeed, the transition changes were repeatedly observed to occur much more rapidly at the surface than within. In other words, the critical cooling rates are there at a maximum. Now, it was noticed that, occasionally, two varieties of troostite were present. One of these was the normal kind, with no crystallographic outline, often figured in text-books ; the other had formed through the breakdown of separate martensite crystallites. An example showing the two together is given in Fig. 17, and it will

¹ *Journal of the Iron and Steel Institute*, 1914, No. I. p. 515.

be seen that the first variety has etched very much darker than the second. These observations suggested that further information might be obtained on the martensitic structures by studying the way in which they decomposed during the process of tempering.

Before describing the results of this inquiry, it will be as well first to mention the tests by which the troostites were identified. For convenience, the variety having an irregular growth will be termed troostite A, and that with margins determined by the crystalline form of the martensite, troostite M. There is seldom any difficulty in recognising the former if austenite or martensite is still present, for the boundary between them is invariably sharply defined. When growing, it seems to spread indiscriminately in patches throughout the solid solution. It etches evenly and darkly with acid reagents, and takes a rather faint stain when treated for ten minutes with a hot alkaline solution of sodium picrate. In the absence of austenite or martensite, however, it is not so easily detected, and may then be mistaken for sorbite. These two constituents gradually merge one into the other, as was plainly seen in specimens of sample C after they had been quenched in hydrogen (p. 319). In the hypereutectoid region, usually at the grain boundaries, some troostite A was present; as the eutectoid zone was approached it increased in quantity and eventually displaced all the martensite. Towards the hypoeutectoid part this uniform troostite was seen, under very high magnification, to change into sorbite, showing discrete carbide particles, but it was scarcely possible to say where one ended and the other began.

The same etching and staining tests were used to identify troostite M. An instance of this variety, stained respectively with acid and alkaline reagents, is given in Figs. 28 and 29. As already stated, it sometimes happens that one part of a surface crystallite will darken while the other remains almost untouched, but, unlike the former, the degree of darkening of this kind of troostite may vary considerably in different crystallites of the same specimen. That orientation is not the cause of this effect was proved by tempering the specimens for a short time at 210° C.; an evenly dark etching equal to that given by troostite A was then obtained. It seems clear, therefore, that the formation of troostite M may occur gradually, and that the extent to

which the martensite has decomposed is indicated by the intensity of the etching tint.

6. *Tempered Martensite, Types I. and II.*—In dealing with the changes produced in tempering the internal martensite structures, types I. and II. will first be considered. Specimens quenched from above the Ac_3 point showed little alteration even after prolonged tempering at $250^{\circ}C.$, except that a distinct black deposit formed when the surface was treated with an alcoholic solution of picric acid. After thirty minutes or more at $400^{\circ}C.$ a uniformly dark structure (osmondite) was obtained, in which scarcely any indication of the original martensitic structure could be found. On tempering at $600^{\circ}C.$, however, this was again clearly to be seen if sufficient care was taken in preparing the surface. It is the author's experience that the specimen needs to be rubbed very lightly on the emery-papers and polished on the cloth with gentle pressure; even then the final stages of this procedure may have to be repeated before the best result is obtained. Unless these precautions are taken, surface drag, due to the application of too much pressure, may completely obliterate the actual structure present.

To illustrate the effects produced in tempering, the following method was adopted. A typical area in each type was marked and photographed. The specimens were then heated *in vacuo* at $600^{\circ}C.$ On removal, the bright untinted surfaces were lightly rubbed on the finest emery-paper to remove the previous etching and repolished. They were then re-etched with a 2 per cent. solution of picric acid in alcohol, and the marked areas photographed a second time. In both types I. and II. martensite similar changes were found to occur; the type I. effect is illustrated in Figs. 20 and 21, and the type II. in Figs. 8 and 9. It will be seen that in each case the outlines of the original structure are preserved, owing to the fact that some of the crystallites have been transformed into ferrite almost free from any visible carbide. With the larger twinned crystallites of type II. this invariably happened. The effect could still better be observed if an entirely new surface was prepared, but of course a direct comparison with the quenched structure was not then possible.

An attempt was next made to find out whether the presence of these ferrite areas was due to a migration of the carbide particles

in tempering. For this purpose thin pieces of sample D, weighing about 0.05 gramme, were rapidly quenched and then inserted on the end of a wire in a furnace at 600° C. for periods ranging from thirty seconds to ten minutes. It was hoped in this way to observe the progress of the migratory movement. A surprise followed, for it was found that even in thirty seconds, which included the time required to bring the piece to the furnace temperature, an effect equal to that seen in Figs. 9 and 21 was produced. Evidently, therefore, either the migration of the carbide particles in the solid material was exceedingly rapid or else the ferrite areas were actually formed in quenching, for in this instance, at any rate, appreciable movement of the carbide by the slow process of solution and diffusion, in so short a time, was incredible.

The possibility of the presence, in martensite, of areas containing much less carbon than the surrounding metal has recently been discussed by Rawdon and Epstein.¹ From certain etching effects they argue that, during quenching, a process similar to selective freezing occurs, whereby the parts last to be transformed are richer in carbon than those of earlier formation. At the same time they confess that such a process is almost inconceivable at the low temperature of martensitic growth. Hallimond² also has lately put forward the idea that in hypoeutectoid steels martensite is produced by a cloud precipitation of exceedingly fine ferrite crystals in the labile region. There is, however, little experimental evidence to support either of these theories; nor do they satisfactorily account for the tempering effects now under consideration. That the appearance of ferritic areas at 600° C. can best be explained as due to an extraordinarily rapid migration of the carbide was shown by the following observations:

(a) As is well known, steels tempered at 400° C. darken almost uniformly on etching. This of itself is strong evidence that an approximately even distribution of carbide exists at that temperature. Further, on heating such specimen for periods of from one to thirty minutes at 500° C. free ferrite in process of formation could then be detected. Unfortunately, the carbide particles were too small to be distinguished, but plain indication of the movement was seen in the gradual emergence of light ferritic areas having the shape of the martensite crystallites.

¹ *Loc. cit.*

² *Journal of the Iron and Steel Institute*, 1922, No. I.

(b) In every specimen a few cases were noted where the carbide existed at the margins of the ferrite in greater quantity than further away, but the effect was not always in evidence. Neither selective freezing nor movement by solution and diffusion would appear to account for this fact. It suggests rather that the particles travel along certain crystal planes more readily than along others.

(c) It has previously been stated that martensite of types I. and II. can be formed in hypereutectoid steels by quenching small pieces in hydrogen only (p. 319). On tempering such specimens for five minutes at 600° C. the result obtained was exactly similar to that given by hypoeutectoid steels. Free ferrite areas were formed, and it was demonstrated by means of photographs that these occupied the positions of the original martensite crystal-lites. This experiment appears to supply conclusive proof that a redistribution of the carbide takes place in tempering, for the presence of any free ferrite in the martensite of hypereutectoid steels is surely out of the question.

Again, in the above specimens direct evidence of migration was found. During the cooling, comparatively large rounded areas of sorbite had been produced in the hypoeutectoid region, and in some instances ferrite had separated along cleavages, giving a structure that could easily be mistaken, under low magnification, for pearlite. After tempering for five minutes at 600° C., it was seen that nearly all the carbide in the completely sorbitic areas had moved to the boundaries, producing a carbide network, as shown in Fig. 18 (Plate XXXVI.).

Thus, from these observations, there seems to be no alternative to the conclusion that these ferrite areas which appear in tempering are due to an exceedingly rapid migration of the carbide particles formed in the earlier stages. The cause of this migration remains obscure. Possibly two varieties of α -iron result from the breakdown of the martensite, and the carbide moves out of one into the other, as soon as viscosity will permit, by a process akin to cataphoresis; but on this problem the investigation has afforded no information.

7. *Tempered Martensite, Type IV.*—While the changes that take place in tempering martensite of types III. and IV. have much in common, they differ considerably from those just

described. In discussing them it will be convenient to deal first with the latter type. As a preliminary, a quenched austenitic specimen of sample H, containing some zigzag martensite, was heated for thirty minutes at 220°C . When etched again after this treatment it was seen that the martensite had changed completely, whereas the surrounding austenite was apparently unaltered. An illustration of the effects observed before and after tempering is given in Figs. 14 and 15 respectively. With sodium picrate an exactly similar result to that seen in Fig. 15 was obtained, so that there could be no doubt that the zigzag martensite had been converted into troostite M. On continuing the investigation, it was found that this decomposition of the martensite could occur within five minutes at 200°C ., but at 180°C . no indication of any change was detected. When once the transition of the martensite had taken place, however, no further change in structure appeared, even after lengthy heating, at temperatures below 250°C . From these observations and the fact that the specimens could be easily indented, it was concluded that the austenite persisted on tempering up to at least 250°C ., and this conclusion was confirmed in the following way.

A specimen of the same sample was quenched from 1050°C . and, after grinding a portion away, the interior was found to be entirely austenite and non-magnetic; martensite was only to be seen at the margins (p. 322). A small indentation was then made in the austenite, which yielded readily to a light blow. On levelling and re-etching the surface, it was found that characteristic zigzag martensite had been formed by the deformation in all the grains in the vicinity of the pop mark, as illustrated in Fig. 7; as a consequence, the piece was no longer non-magnetic in the centre. The identity of this martensite with that produced in quenching was proved by the fact that it could be quickly changed to troostite M at 200°C ., and also behaved similarly at higher temperatures. It was clear, therefore, that this effect—namely, the formation of martensite by cold-working—could be used as a test for austenite.¹ Accordingly, a specimen which had

¹ In connection with the formation of martensite from austenite by deformation, it is of interest to note an observation of Benedicks. He says: "It has been demonstrated that an unetched surface of a martensite-austenite specimen, when allowed to stand, even at ordinary temperature, is altered in so far as that relief

been tempered between 200° C. and 250° C. was indented, with the result that here also martensite was obtained. In the same grains near the indentation, the dark, decomposed original crystallites and light newly formed ones were to be seen together, thus proving that austenite was still present.

This persistence of austenite up to 250° C., while the martensite at once changes to troostite M, was not altogether surprising, in view of the work of Aall and others,¹ who have shown that, unlike martensite, austenite is stable in certain quenched nickel steels up to about 500° C. In the present case, however, troostite A appeared in austenite when the same specimen which had previously been heated held between 200° C. and 250° C. for three hours was heated for fifteen minutes at 280° C. Within many of the rounded patches of this troostite A, the zigzag troostite M could be plainly seen when the surface was treated with either acid or alkaline reagent. An instance is shown in Fig. 22. This result was quite unexpected, as it was thought that the two kinds of troostite, when in contact, would be indistinguishable. On a further tempering of the same piece for periods of fifteen minutes, at temperatures which were increased by 50° C. each time, the shapes of the zigzag crystallites still remained distinct and could be readily detected even up to 700° C. Fig. 24 shows the effect obtained with sodium picrate after tempering at 400° C. Aggregations of the carbide had occurred at the boundaries, along the median line, and even on the parallel cross-lines of the crystallites—a fact which lends no support to the suggestion of Rawdon and Epstein,² that these commonly occurring markings are really fine cracks.

After tempering at 700° C. for three minutes the structure developed with picric acid is shown in Fig. 16. The zigzag crystallites etched much darker than the surrounding material, but with sodium picrate the reverse was the case. As far as could be seen, this darkening by acid reagents was due to the presence of exceedingly fine carbide particles, for, on heating the specimen a longer time at the same temperature, the particles grew larger, and it was then apparent that they were less numerous

forms appear, owing to the progressive transformation of the austenite into martensite" (*loc. cit.*, p. 322). This particular effect has not been observed by the author.

¹ *Stahl und Eisen*, vol. xliv., No. 36.

² *Loc. cit.*

in these parts than in the surrounding metal. Frequently a thin band of carbide was visible at one of the margins, but whether these tempering effects were caused by a partial migration of the carbide, or simply by solution and diffusion in the ferrite, could not be ascertained. That they were not due to the operation of a process during quenching analogous to selective freezing, as Rawdon and Epstein have imagined, was proved by the fact that exactly the same effects were produced by tempering martensite which had been formed through deformation of the cold austenitic sample (p. 330).

The difference between the two kinds of troostite is made clear in the above observations. Troostite A originates directly from a breakdown of the austenite without any intervening martensitic structure appearing, whereas troostite M represents the first stage in the decomposition of the latter. Troostite M can evidently form at a lower temperature than troostite A, and their behaviour in tempering, when they occur together, proves that they are not physically identical. Portevin and Garvin¹ have shown that the temperature of formation of troostite A, in moderately rapid quenching, lies at about 650° C., but clearly, from the above result, it can appear at a much lower temperature, provided that austenite is still present in the steel.

Another example, in which the two varieties of troostite were present together, is depicted in Fig. 4. This represents a portion of the hypereutectoid region in a section from sample C after it had been quenched in hydrogen only. Three dark areas of troostite A are to be seen, and on the largest of these needles of troostite M have developed by decomposition of some of the adjacent martensite crystallites. This effect was repeatedly observed in these hydrogen quenched samples, and is significant in that it strongly indicates inoculation of the martensite by the troostite A. If such, indeed, has been the case, then obviously martensite must be a solid solution. From the work of Portevin and Garvin, the order of formation of the constituents shown in Fig. 4 would be as follows : first, some austenite was transformed to troostite A at about 650° C. ; next, the remainder was converted into martensite in the neighbourhood of 300° C. ; and, finally, at a still lower temperature, the needles of troostite M appeared.

¹ *Loc. cit.*

One other point arising from these observations should here be mentioned—namely, that martensite, troostite A, and eutectoid pearlite are not consecutive products in the transformation of austenite, as is still occasionally stated, but alternative. True lamellar pearlite, for example, never crystallises either from martensite or troostite, but always grows directly from a solid solution, which would yield austenite if it could be cooled with sufficient rapidity. An instance is seen in Fig. 12. It will be observed that lamellar pearlite has been caught in process of formation at one side of the solid solution area and that no troostite intervenes.

8. *Tempered Martensite, Type III.*—Although the changes that occurred in tempering martensite of type III. were similar in many ways to those seen in type IV., yet in certain respects they differed. Tempered at 400°C. , steels containing type III. martensite gave a uniform dark-etching sorbite, in which but little indication of the original structure could be detected. As the temperature was increased to 550°C. , the twinned crystallites and lenticular plates characteristic of type III. began to appear again, and could be located by a darker etching when picric acid was used. An example is given in Figs. 39 and 40, which show the same area in a specimen of sample G before and after tempering for five minutes at 600°C. Here, as was the case in type IV., the carbide particles appeared to be smaller in the darker parts, and also a thin border of carbide was sometimes observed on one side. But on tempering above 650°C. these indications of the original martensite usually disappeared; in fact, in the lower carbon specimens, they vanished in the neighbourhood of 600°C. But the border-line of carbide remained, and so served to mark the place where a crystallite had formerly existed.

When working with the case-hardened sample C it was of interest to note how, in the region of transition of type III. to type II., the crystallites etched darker or lighter than the matrix, according to which type they happened to belong. The absence of any pronounced migration of the carbide in type III., while it quickly occurred in type II., thus afforded a useful means of distinguishing crystallites of the one type from the other when they were adjacent. This contrast in behaviour must undoubtedly be

set down to a difference in the nature of the material surrounding the crystallites in the two cases.

With type III. martensite, the tempering effects requiring most consideration, however, are those which occurred at lower temperatures. Up to $180^{\circ}\text{C}.$, as in the case of type IV., no alteration could be observed, but at about $200^{\circ}\text{C}.$, even after a very short heating, the original structure was completely obliterated ; instead, that illustrated in Fig. 23 was obtained with either acid or alkaline reagent. The dark constituent there shown has previously been depicted and mistaken by Rawdon and Epstein¹ for martensite, but it is unquestionably troostite. When seen under the microscope, it has a very characteristic lattice appearance. This structure was also occasionally found in imperfectly water-quenched samples, but in these the degree to which the lattice darkened varied considerably in different grains, evidently, as previously remarked (p. 326), according to the extent to which the martensite had decomposed. A typical example is seen in Fig. 6. During quenching a very slight retardation was sufficient to cause this structure to form, but to produce the same momentary conditions in tempering was obviously impossible. It was not, therefore, to be expected that any tempered specimen would show a similar gradation in etching tints.

Careful observations made on specimens which had been tempered just below $200^{\circ}\text{C}.$ demonstrated that the parts which were being transformed into the lattice-troostite included the arrow-head twins and elongated crystallites of the original martensite ; the angular unetched areas of the new structure were seen to be invariably derived from the dark infilling material (Fig. 39). This rapid breakdown of the martensite crystallites in type III. was clearly identical in character with that which was found to occur in type IV. In order to examine the effect produced where one type merged into the other, a section of the composite sample was quenched and heated for five minutes at $210^{\circ}\text{C}.$ An area, including the whole of the hypereutectoid region, of this tempered specimen is shown in Fig. 38 (Plate XXXIX.). Up to about 0.70 per cent. of carbon, no alteration was noticeable in the acicular martensite ; then, as the type III.

¹ *Loc. cit.*

region began, troostite made its appearance with minute angular areas of the white constituent embedded in it. With increasing carbon content these gradually became larger, until finally, when the 2.35 per cent. zone was reached, they formed the austenitic structure containing the dark zigzag troostite given by type IV. martensite.

From the progressive diminution in the quantity of austenite in the above specimen, until only the white constituent in the interstices of the lattice-troostite was to be seen, it was judged that the two were one and the same substance (a). This conclusion was also supported by the fact that the temperatures of their transformation to troostite were found to be almost identical. Below 250° C. both seemed to be stable. Still further confirmation was obtained in another experiment. A small specimen of sample H, containing both troostite A and type III. martensite, was prepared by quenching, from 1000° C., in hydrogen only. No type IV. martensite was present. On tempering this specimen for five minutes at 210° C. a striking effect was produced. The areas of troostite A had spread considerably, and the untransformed parts now exactly resembled austenite with tempered type IV. martensite, as shown in Fig. 35. Clearly, in this instance, tempering type III. martensite had caused the appearance of a white constituent indistinguishable from the austenite which persisted with tempered type IV. martensite (p. 331).

With the gradual decomposition of the white constituent on tempering the lattice structure above 250° C., the original martensite crystallites could again be located by careful etching, as shown in Fig. 25, and, as previously stated, they could still be detected after tempering at 600° C. It is remarkable that the whole of the troostite forming the lattice-work did not behave like troostite M; but the fact remains that, in further tempering, no trace of the dark lattice structure could be observed at any subsequent stage. Now, a comparison with the behaviour of type IV. martensite will show, that the entire areas of the infilling material, and not merely those portions which changed into the white constituent, tempered like the austenite, for only the original martensite crystallites kept distinct. It might consequently be inferred that these areas really consist altogether of austenite, as indeed has been surmised by several authors (b).

Martensite specimens which contained a large amount of the infilling material were, however, invariably much harder than mixtures of austenite and martensite, nor could any constituent which etched like austenite be detected in them (c). • Thus, while observation (a) above indicated this infilling material to be partially, and (b) wholly, austenite, (c) indicated it to be martensitic in character. In order to meet this difficulty, the suggestion is here advanced that the infilling material of type III. represents an intermediate stage in the transition from austenite to martensite, and that, in tempering at 210° C., austenite comprising the white constituent is actually re-formed from part of it, while the remainder changes to a troostite, giving, with the troostite M from the martensite crystallites, the peculiar lattice structure.

9. *Tempered Surface Martensite.*—The changes observed in tempering the surface martensite require but brief consideration, since they were of exactly the same order as those produced internally. Fig. 31 (Plate XXXVIII.) shows some crystallites which were formed on a quenched specimen of sample H. Fig. 32 shows the same area after the surface had been treated with Kourbatoff's reagent. Tempered for five minutes at 210° C., these crystallites were transformed into troostite M, as shown in Fig. 33, and, when heated *in vacuo* at 650° C., they could still be discovered by their darker appearance, as illustrated in Fig. 34. A comparison of these results with those given by type IV. martensite will show that they are essentially alike.

Again, Figs. 28 and 29 (Plate XXXVIII.) reproduce an area of surface crystallites formed on the hypereutectoid portion of the case-hardened sample C and etched respectively with sodium picrate and Kourbatoff's reagent. After tempering at 600° C. for five minutes, the shapes of the crystallites were still well defined by the arrangement of the carbide particles, as shown in Fig. 30. It will be noticed that the ferrite areas in the latter are, for the most part, in the positions occupied by the troostite M areas in the other two, from which it is clear that there has been a rapid migration of the carbide. Further experiments indicated the temperature of this migration to be between 400° C. and 500° C. Now, as previously shown (p. 327), an equally rapid migration, although at a somewhat higher temperature, was found to occur in tempering types I. and II. martensite. Evi-



FIG. 2.—Surface martensite, etched. $\times 850$.



FIG. 3.—Surface martensite. $\times 950$.

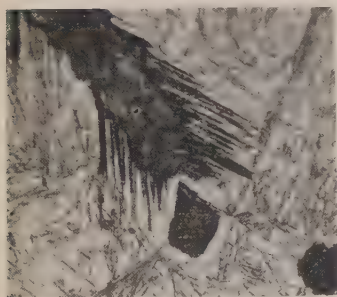


FIG. 4.—Martensite, troostites Λ and M . $\times 850$.

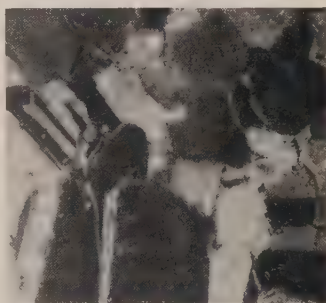


FIG. 5.— γ -iron twins on surface. $\times 850$.

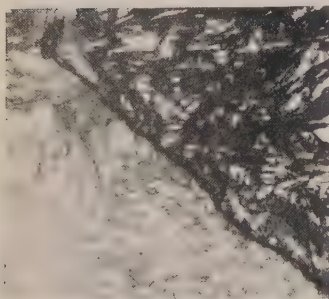


FIG. 6.—Lattice-troostite. $\times 850$.



FIG. 7.—Austenite with type IV martensite formed by deformation. $\times 140$.



FIG. 8.—Type II marten-
site. $\times 850$.



FIG. 9.—Same, tempered
at 600°C . $\times 850$.

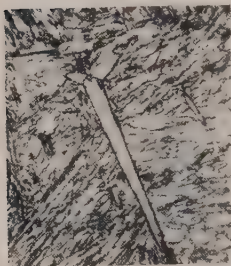


FIG. 10.—Type I marten-
site with large crystallite.
 $\times 950$.



FIG. 11.—Surface marten-
site. $\times 140$.



FIG. 12.—Ferrite, marten-
site and pearlite. $\times 850$.



FIG. 13.—Type II marten-
site. $\times 850$.

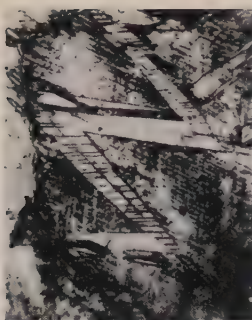


FIG. 14.—Type IV martensite. $\times 850$.

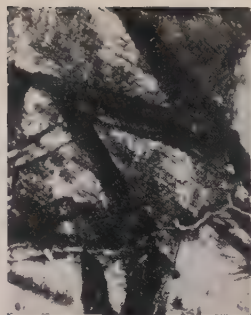


FIG. 15.—Type IV martensite tempered at 210°C . $\times 850$.



FIG. 16.—Type IV martensite tempered at 700°C . $\times 950$.

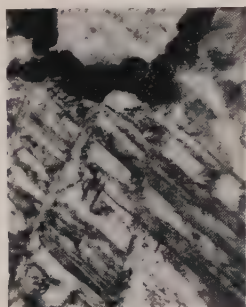


FIG. 17.—Surface martensite with troostites A and M. $\times 950$.

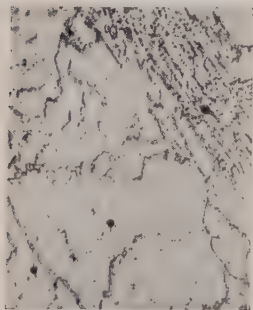


FIG. 18.—Sorbitic area after tempering at 600°C . $\times 850$.



FIG. 19.—Ferrite with structureless and acicular martensite. $\times 850$.

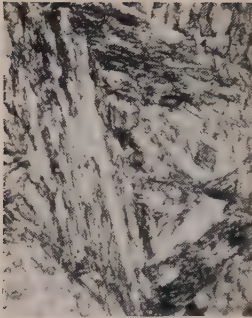


FIG. 20. - Type I marten-site. $\times 850$

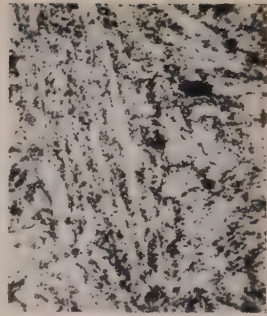


FIG. 21.—Same, tempered at 600° C. $\times 850$.

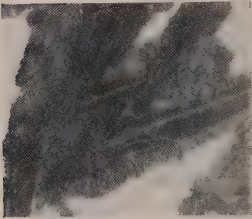


FIG. 22.—Austenite, troostites A and M. $\times 850$.

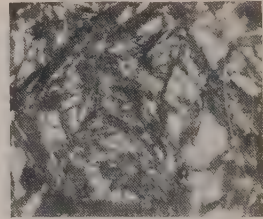


FIG. 23.—Lattice - troostite stained with sodium picrate. $\times 850$.

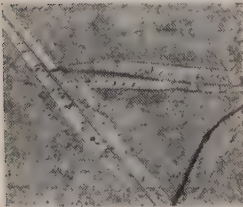


FIG. 24.—Type IV marten-site tempered at 450° C. $\times 950$.

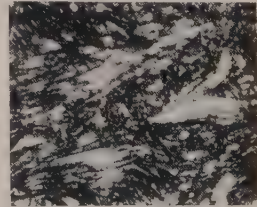


FIG. 25.—Type III marten-site and lattice-troostite. $\times 850$.

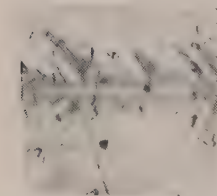


FIG. 26.—Surface marten-site crystallite. $\times 1450$.



FIG. 27.—Same, etched with Kourbatoff's reagent. $\times 1450$.



FIG. 28. — Surface martensite and troostite M stained with sodium picrate. $\times 850$.



FIG. 29. — Same, etched with Kourbatoff's reagent. $\times 850$.

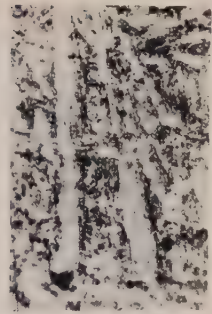


FIG. 30. — Same, tempered at 600° C., etched with picric acid. $\times 850$.



FIG. 31. — Surface martensite. $\times 850$.



FIG. 32. — Same, etched. $\times 850$.



FIG. 33. — Same, tempered at 210° C. $\times 850$.

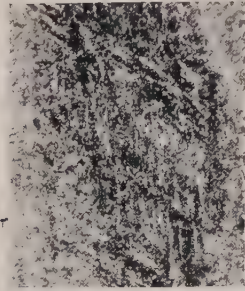


FIG. 34. — Same, tempered at 650° C. $\times 850$.



FIG. 35.—Austenite with troostites A and M. $\times 850$.



FIG. 36.—Surface martensite on electrolytic iron. $\times 850$.

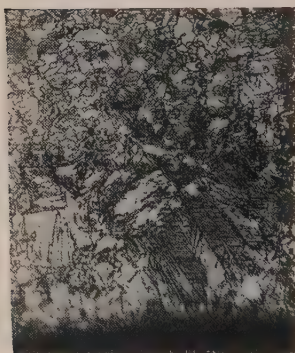


FIG. 37.—Marginal martensite in soft steel. $\times 70$.



FIG. 38.—Austenite and troostite. $\times 140$.



FIG. 39.—Type III martensite. $\times 850$.



FIG. 40.—Same, tempered at 600°C . $\times 850$.

dently, therefore, crystallites belonging to these latter types had appeared on the surface of the hypereutectoid region instead of type III. normal for the interior. This result is to be accounted for by the greater critical cooling rates of the transformations which undoubtedly obtain at the surface. The chief point to emphasise, however, is the exact correspondence in the behaviour of the external and internal crystallites, a fact which makes their structural identity practically certain.

10. *Formation of Martensite.*—Evidence was given, in considering the effects obtained in quenching, showing that the surface crystallites are composite in character, and in all probability twinned (p. 323). Now, since the external and internal crystallites have been found to be of the same nature, it is to be expected that twinning should also be seen in the latter. That such is the case in types III. and IV. is unmistakable, for both the zigzag and arrow-head crystallites are manifestly twinned, but it is not so clear in the second growth acicular martensite found in types I. and II. Although the configuration of this martensite exactly resembles that formed on the surface, it lacks a clearly defined twinned structure. If, therefore, these internal martensites originate in a repeated twinning during the allotropic change from γ -iron to α -iron, as, indeed, seems to be the case, the question arises as to why the acicular variety does not show it more distinctly. In answer to this question the following tentative explanation is advanced.

It is well known that the transformations which give rise to martensite are accompanied by an increase in the volume of the steel, and this probably accounts for the fact that the surface martensite crystallites always stand out in relief. Freedom of movement at the surface, however, is much less restricted than within, and it would seem as though the internal stresses due to volume expansion at about 300°C. , while the interior is still contracting, are sufficient seriously to distort the twinned structure as it forms. Consequently, its general configuration remains, but the separate twinned acicular crystallites do not appear as well defined as on the surface. With increasing carbon content, the degree of distortion will tend to diminish, owing to the progressive hardening of the metal, and instead numerous cracks may develop. Evidence supporting this explanation was obtained, for example,

when type II. martensite was produced in a hypereutectoid steel by quenching in hydrogen only; the individual crystallites of the acicular structure could then always be clearly identified.

Finally, it should be remarked that no observation has been made during the investigation which would suggest that martensite is other than a solid solution, provided it is agreed that austenite is such, for the two behave very similarly in several ways. Martensite, like austenite, shows no sign of staining after prolonged treatment with sodium picrate. Like austenite, it breaks down into troostite; indeed, the stages of the process can be followed. Moreover, as with austenite, this precipitation of carbide can apparently be brought about by inoculation, an observation which of itself seems sufficient to establish proof of solid solution. Also, martensite can be produced from austenite simply by cold deformation.

These facts all afford evidence of a solid solution and, since carbide is not appreciably soluble in α -iron, it follows that some other form of the metal must be present. This inference is supported by the fact that, with the possible exception of the Neumann lines, α -iron shows no tendency to twin, whereas the martensitic structure is almost certainly the result of repeated twinning along several planes in each grain. The further conclusion is reached, therefore, that martensite is a solid solution of carbide in a transitory form of iron of strong twinning tendency, which appears at an intermediate stage in the transformation of γ -iron to α -iron.

Since the completion of this paper by the author, an important work has been published by F. F. Lucas on the "Microstructure of Austenite and Martensite."¹ This paper forms an interesting study of the application of high power metallography to the study of the structure of austenite and martensite, reference to which should be made by anyone desiring to pursue the subject further.

The author desires to record his indebtedness to Mr. A. F. Hallimond, M.A., and Mr. B. Jones, M.Met., for several suggestions which were helpful in preparing the manuscript.

¹ *Transactions of the American Society for Steel Treating*, December 1924, vol. v. p. 669.

DISCUSSION.

Colonel N. T. BELAIEW, C.B. (London), said the paper was one of very great interest and importance, particularly if taken together with the paper that had been read by Mr. Lucas. Some time ago two very important papers on the subject were published by Mr. Lucas—one in December of 1924, in the *Proceedings of the American Society for Steel Treating*, and the other one quite recently in Sheffield, read by Dr. Desch on behalf of Mr. Lucas. There were some points raised by Mr. Whiteley which, as far as he could see, also could be to a certain extent proved or perhaps sometimes also modified by what had been done by Mr. Lucas.

The first very important point raised by Mr. Whiteley was his distinguishing four types of martensite, and next to that he proceeded to consider some of those types, and gave very interesting details with reference to what he called structureless martensite. That was again a small point which could be taken in conjunction with Mr. Lucas's researches. He understood that Mr. Lucas considered that martensite was always being stained by the same reagent, picric acid, which Mr. Whiteley mentioned as sometimes not staining some parts of the martensite. He (Colonel Belaiew) had tried to find an explanation, because he considered that both could be right. In his experience martensite was always etched as Mr. Lucas showed it. On the other hand, he was quite convinced that Mr. Whiteley was also quite right when he mentioned some areas of martensite as not being etched by the same reagent. Following up rather closely the argument of Mr. Whiteley, some explanation of that fact might perhaps be found in the fact that the chemical composition of the areas which, as Mr. Whiteley said, were not being touched by the reagent, was different. Mr. Whiteley showed that the concentration of carbide in some of the areas was different. It was not impossible that the areas rich in carbides and rich in γ -iron were exactly the martensite areas which could not be etched, but those areas apparently were not martensitic but to a large extent austenitic. Could Mr. Whiteley give some additional explanations on the matter? If his suggestion was wrong he still supposed that the difference between the etching reagent might be found in the difference in chemical composition.

The next point which was very interesting to consider in Mr. Lucas's paper and Mr. Whiteley's paper was that Mr. Whiteley considered two kinds of troostites, troostite A and troostite M. Mr. Lucas had also described two types, one which he called nodular and the other which he called floccular. In some of the pictures given by Mr. Whiteley there were some slight features which also were of interest from the fact that in Mr. Lucas's paper they were developed at some length—he referred

to the so-called midribs. Mr. Lucas defined the midrib in the marten-sitic needles as that which etched more readily than the other part of the needle. Considering Fig. 24 (Plate XXXVII.) in Mr. Whiteley's paper, the midribs would be quite easily seen in both the needles. Some of Mr. Whiteley's references to the lines could also be explained by comparing his photographs with the splendid high-power photographs shown by Mr. Lucas. He considered that those photos were in substantial agreement. Mr. Whiteley stated that "It should be remarked that no observation has been made during the investigation which would suggest that martensite is other than a solid solution, provided it is agreed that austenite is such, for the two behave very similarly in several ways." Perhaps owing to his old-fashioned reluctance to consider as solid solutions such systems which according to the older theoretical views could not be considered as such, he (Colonel Belaiew) found some difficulty in subscribing to that view. Even from the modern standpoint there was no difficulty at all in regarding austenite with the lattice structure as a solid solution in connection with γ -iron, but there was some difficulty in considering α -iron, martensite with carbon, as a solid solution. He would still prefer to consider austenite as a solid solution and martensite as not. Mr. Whiteley referred to the fact that the carbon content in some of the needles was different, which was also confirmed by Mr. Lucas, and to that observation he would like most heartily to subscribe, because it seemed to him to be quite in accordance with the views expressed some time ago on the actual octahedral structure of martensite; there was actually some deposition of various layers parallel with the four faces of the octahedron. Sometimes people found it difficult to understand what were the layers which formed the structure of martensite, but now it could be seen from Mr. Whiteley's and Mr. Lucas's papers that there was solid ground to suppose that the first layers were of a rather different chemical composition. He was sure all the members were indebted to Mr. Whiteley for his paper, for the splendid photographs he had shown, and for the interesting experiments he had carried out.

Professor F. C. THOMPSON (Manchester University) said he agreed very heartily with the majority of Colonel Belaiew's observations. One point on which he ventured to disagree, however, was in considering martensite as a solid solution. He still felt that, so far as the present evidence was concerned, there were some good reasons for believing martensite to be a very highly supersaturated solution of carbon or carbide in α -iron. The point that had been made by Colonel Belaiew that the needles in an austenite-martensite structure were of different carbon content from the material from which they separated and from that in which they were embedded was by no means a new one. The first reference to it, so far as he knew, was by Hanemann in *Stahl und Eisen* in 1912, when photographs were shown very similar to Figs. 29 and 30 on Plate XXXVIII. It would be seen that, after tempering, the areas

represented by the martensite needles were very much freer from carbide than was the material in between. Hanemann showed exactly similar things. The evidence seemed to be so strong that it could hardly be controverted that the needles of martensite were definitely of different carbon content from the austenite. There were two points in the paper which particularly appealed to him, the first being in connection with the whole-hearted acceptance of the twinning theory of martensite. That was propounded by Professors Carpenter and Edwards, and it was, practically speaking, the position Mr. Millington and he (Professor Thompson) had been compelled to adopt against their preconceived notions. The other point equally interesting was that Mr. Whiteley on two occasions emphasised the fact that the structural changes which took place through quenching were initiated at the surface. On p. 322 he dealt with that point with regard to martensite, which, however, was not new, since Benedicks had shown it many years ago. Mr. Whiteley also made the observation on p. 325 which, so far as he could gather, was new, that the formation of troostite was also a surface phenomenon. He did not think he could quite agree with Mr. Whiteley's statement on p. 322, where he said that in both cases the explanation appeared to be that martensitic growth had been induced at the corners and edges by the greater stresses produced in those parts. With regard to the result, he was in perfect agreement with Mr. Whiteley, but so far as he could see the explanation of the result was not that the stress was greater at the surface and edges, but that at the surface and edges the material was freer to deform under the stresses which were present. There were very many points in the paper which might be taken up with advantage, but he thought Mr. Whiteley had done a very real service in his definite proof that martensite was formed in quenching at a low temperature. He believed that that was what the vast majority of members would accept without the slightest hesitation, but it was a fundamental matter in connection with the view still being held, chiefly by Japanese workers, that the formation of pearlite from austenite took place through the martensitic zone. For that explanation there was absolutely no proof at all, but certain workers were still harping on that theme, and the work of Mr. Whiteley went a long way to provide very definite experimental evidence that such a formation of pearlite was quite impossible, and it was a point of the very greatest value. It was very difficult in a way to discuss the paper by itself, and Colonel Belaiew had been compelled to discuss it in connection with the extremely valuable paper of Mr. Lucas. If he might be allowed he should like briefly to consider Mr. Whiteley's paper with the corresponding paper by Mr. Enlund. Both in Mr. Whiteley's paper and in Mr. Enlund's paper the suggestion was made—if not explicitly, certainly implicitly—that the change from austenite to troostite or sorbite was very definitely discontinuous. It would appear that from the point of view of physical or mechanical properties there were definite discontinuities. Mr. Enlund had proposed explanations. He (Professor Thompson) found the very greatest difficulty in accepting

in their entirety the explanations put forward. The greatest difficulty was in believing that martensite in the needles of an austenite-martensite structure changed to troostite at a temperature of 90°C . It was a metallographic point, but there was one practical fact which immediately put out of court such an hypothesis. It had either to be assumed that the martensite in an austenite-martensite structure behaved, for a reason quite unexplained, quite differently from an ordinary martensite, or that if an ordinary plain carbon tool steel were taken and tempered in boiling water it was turned to troostite. The latter was so obviously untrue that there was no need to discuss it. He could not help feeling therefore that the rather dogmatic conclusion that martensite tempered to troostite at or around 100°C . was unjustifiable. A certain change took place, however, and he threw out for consideration the following suggestion. Assuming that, normally speaking, the breakdown of the solid solution was continuous, there was the possibility of abnormalities being apparently introduced into that continuous change by changes in the α -iron itself. That would not take place if it was a purely austenitic steel, but so long as martensite was present there was α -iron. He thought he could claim to have shown in conjunction with Mr. Whitehead and Goffey that there was a series of changes taking place in α -iron when it was heated to comparatively low temperatures. If those occurred it could be imagined that when they took place there was a sort of shudder passing through the martensite as the result of changes in the α -iron. Thus a normally progressive change might be momentarily accelerated, and he suggested that the change which Mr. Enlund had shown on p. 310 in connection with the resistivity drop at about 110°C . was possibly only the effect of the change in the iron, and not a definite and specific change in the martensite. The difficulty of accepting the dogmatic statement that that change was due to the change from martensite to troostite was accentuated by the change that Mr. Enlund himself produced. Comparing the top curve of Fig. 14 with the curve of the 0.88 steel quenched at 800°C ., it would be found that the change at 110°C . was of the same order of magnitude in each case. In the case of the saturated steel quenched at 800° there was essentially martensite, and in the case of the higher carbon steel quenched at 1050° there was a predominating amount of austenite. It would therefore be expected that the martensitic change at 100° would be very much smaller in the case of the top curve of the austenitic material than in the case of the lower one, but as a matter of fact the order of magnitude was the same. There was very good reason at any rate to doubt for the moment the conclusion that martensite tempered to troostite at 100°C . He agreed with the conclusion that Mr. Enlund came to in his paper where he said: "Those all-carbon steels quenched in water in the ordinary way contain some austenite." That he believed to be absolutely true. In connection with the treatment of some steels in practice, the recognition of that fact was a point of very considerable importance indeed.

Professor HOYT (Schenectady) said he wanted to present what to his mind was a brand-new idea, but before doing so he thought it would be well to review some of the recent work which had been done in the elucidation of the general problem of martensite. The X-ray evidence had been rather disappointing. It had been found from the X-ray examination that the so-called martensite had the α -iron lattice, and that the α -iron was either extremely fine-grained or that the lattice was distorted. On calculating the position of the carbon atoms it was at once evident that the carbon atoms could neither completely replace the iron atoms nor be completely tucked in between the iron atoms. Some of them replaced iron atoms and some of them were tucked in between, giving a picture which was not very satisfactory. The microscope had been used very extensively and was still being used in connection with the question, but it had not led to definite positive results. It was possible to study the behaviour of the steels and so forth, but when it came to the very fine points the solution did not seem to be given simply by microscopic evidence. Thermal evidence had been also extremely valuable but again not conclusive. He was referring to the work of Portevin and Garvin, who found that troostite formed in the neighbourhood of 600° , and martensite at 300° . In addition, quite a number of theories had been put forward which correlated all the facts more or less satisfactorily.

With regard to the new idea he had mentioned, he had just visited Dr. Hanemann's laboratory in Charlottenburg. He had found that Dr. Hanemann was continuing his work on the subject, and as the result of an idea conceived some two or three years ago, and since very carefully worked out, had arrived at a new conception of quenched steel. Dr. Hanemann had used the thermal evidence as the basis of a diagram he had worked out. First of all, he found a critical point in pure iron which occurred during quenching. Secondly, he found from microscopic evidence that martensite in an ordinary piece of quenched steel was not a single-phase material but a two-phase material: it was composed of a solid solution of iron with about 0.08 per cent. of carbon and a solid solution or compound containing about 0.9 per cent. of carbon. In the hypereutectoid steels there was martensite plus austenite in the way which had been considered that morning, and which was fairly well known. He would not attempt to review the evidence which Dr. Hanemann was about to publish—the evidence which formed the foundation of his diagram. He had read the original paper and discussed the matter with him a number of times, and he was bound to say that the evidence seemed quite clear and conclusive that a diagram of that type must be considered; in other words, that the diagram indicated the phase changes which took place in steel during quenching. As far as the X-ray evidence went there was no new evidence available by which a difference between eta and epsilon and pure iron could be ascertained. But by examining a series of steels varying in carbon content, it was perfectly evident that there were two phases present, one of which

continually decreased in amount and the other continually increased in amount. The phase with 0.9 per cent. carbon was extremely interesting, because it seemed to him that that was what metallurgists had been thinking of as martensite; in other words, martensite should be confined to the particular composition of 0.9 per cent. carbon, corresponding with Fe_{24}C , and indicating a reversion to Professor Arnold's original idea that the cause of hardness was due to a sub-carbide of iron. The shift in carbon content of that phase at lower temperatures was not definitely known, but it was interesting to note that those two lines (giving the martensite-austenite equilibria) accounted for the fact that austenite changed into martensite in liquid air. As Dr. Hanemann had shown there was never a complete transformation from austenite to martensite, so that there was simply an equilibrium between the two phases, the equilibrium depending upon the temperature. At liquid air temperature there were appreciable amounts of martensite left. It was not a change from a metastable to a stable condition, but simply a shift in equilibrium. That work of Dr. Hanemann had not yet been published, but it was coming out very soon in *Stahl und Eisen*, and, he thought, might also appear in English.

Professor WILLIAM CAMPBELL (Columbia University, New York) said that with regard to the reference to Mr. Lucas's paper on the microstructure of austenite and martensite, published in December by the American Society for Steel Treaters, the photographs at 3000 and 6000 diameters shown were good, but were only second rate compared with the photographs he was taking at present. Some of those photographs were used by Dr. Matthews, sometime Carnegie Scholar and Medallist of the Iron and Steel Institute, in February, when he delivered the Howe Memorial Lecture before the American Institute of Mining Engineers. Those photographs showed the absolute details of structure. They showed what might be called the microstructure as compared with ordinary photographs at 1000 diameters might be described as relatively only the macrostructure. He was impressed by the fact that even if martensite were divided up into four different types those types were similar, but when people spoke of two types of troostite there was no similarity between them. It was calling two absolutely different things by the same name when both those structures were called troostite. He referred especially to typical troostite produced on quenching, compared with so-called troostite produced on tempering. The slip-inference theory of Jeffries and Archer explained very well to the ordinary engineer the reason for hardening of steel, by considering all the structures, from martensite through troostite, sorbite to pearlite, as mechanical mixtures in different states of subdivision of α -iron and of iron carbide. When, however, the typical photographs which had been published since the time of Roberts-Austen and Osmond were examined (and even to-day there were no better photographs than the originals taken at that early time), the conclusion was arrived at that micro-

structure alone would not solve all the difficulties, and it was necessary to call in not only the expert in X-ray work, but also the newer group who were working along the magnetic and the electric conductivity lines. Dr. Matthews had shown in some nickel and nickel-chromium steels some very anomalous results, in which material quenched in oil was harder than that quenched in water, and that the magnetic and electric conductivity properties were also abnormal. Those who were doing magnetic and electric conductivity research should take up the problem and help to elucidate the variations in structure and properties in hardened steel.

Mr. A. F. HALLIMOND (London) said the papers by Messrs. Whiteley and Enlund together represented a valuable addition to the description of the microstructure of quenched steels. On the theoretical side, however, he was unable to accept the interpretation put forward by Mr. Whiteley. In the first place, while the mercury quenching seemed adequate in the early stages, when the piece entered the mercury with reasonable speed, it could not be so rapid at the finish, when the piece was floating in liquid, the condition of turbulent flow against the steel surface being no longer fulfilled. As a result, while there had been no difficulty in passing the higher critical points, there seemed a tendency to obtain a slightly more advanced decomposition in the neighbourhood of Ar'' , and austenite had only been preserved at somewhat higher carbon values than those assigned by Portevin. The production of crystallites, and of the labile shower, on the other hand, were very well illustrated, especially in Fig. 38. Both Le Chatelier and Benedicks found that mercury was less effective than water, the former assigning that fact to the specific heat, the latter to the latent heat. In the second place, Mr. Whiteley considered that the facts he recorded were inconsistent with the "supersaturation theory" and had revived the idea of a metastable solid solution, advanced some years ago by Benedicks and again by Portevin and Chevenard.¹ In direct conflict with the well-known X-ray results of Westgren, who proved that martensite had the α -lattice, Mr. Whiteley was compelled to invent a new "transitory form" of iron to account for that solution. After a very careful reading of the papers, he (Mr. Hallimond) had been unable to find any fact which was not completely explicable in terms of the supersaturation theory which he put forward in 1922.² Indeed, there were some details which in themselves seemed to necessitate the rejection of the solution theory and the acceptance of Westgren's view that martensite was a colloid suspension of carbon in a ferrite—for example, the coarser crystals of martensite form above the Ar'' point could not, therefore, represent a masked transition. The potential of the ferrite was, of course, much altered, and that conferred some of the properties of a solution. In his own paper no reference was made to the state of the carbide in martensite,

¹ *Revue de Métallurgie*, 1921, vol. xviii. pp. 425-444.

² *Journal of the Iron and Steel Institute*, 1922, No. II. pp. 359-379.

for little definite evidence was available. Mr. Whiteley's experiments now proved that the carbide was uniformly distributed throughout the crystals. That condition was foreshadowed in his diagram, for a horizontal line was drawn about 600°C. and was marked "crystallisation of cementite suspended (in rapid cooling)." Obviously if the carbide were immobile below 600°C. it was unlikely to be redistributed at 300° , even in α -ferrite, and the atoms must therefore remain suspended in the α -lattice after shower precipitation had occurred. The presence of that mechanically included matter did not alter the nature of the precipitation, which was still correctly described as a labile shower of α -ferrite. Enlund's two transition points corresponded with the two steps in the curve for "missing carbon" (in quenched steels carbon = 0.54 and 0.59, after tempering) published by Mr. Whiteley in 1917.¹ The first step, at 100° to 150°C. , was a small drop in missing carbon accompanied by a small reduction in hardness, and no doubt represented the resumed decomposition of the crystallites. The second step (200° to 250°C.) was much greater, but was accompanied by no change in the hardness; presumably, therefore, it corresponded with a change affecting the carbide but not the ferrite. That would agree with the view that it was the coagulation point of the suspended carbide. But the extreme hardness of the sample indicated that the carbide was not present as austenite; the photograph showed a structure corresponding with that now termed martensite II. to III., so that the ground-mass was presumably "white-etching martensite." Enlund's transition point occurred in steel of that composition (0.54 carbon), and it would therefore follow that the transition occurred equally with white-etching martensite as well as with austenite. If that were the case, there was no longer any need to infer the presence of γ -iron in quantity in quenched low-carbon steels. The transition point varied but little with the concentration, a property which again agreed with the view that the change resembled a coagulation. With regard to *martensite* and *troostite*, all the structures now figured were in accordance with the supersaturation diagram. With increasing carbon content there was, first (up to 0.60 carbon), a martensite formed at rather high temperatures with a long cooling range, consequently of coarser grain, but ill-preserved and therefore dark-etching; secondly (0.60 to 0.75 carbon), martensite formed near 300°C. with a fine structure and short cooling range, consequently white-etching and very hard; above 0.75 carbon the martensite line approached close to the limit determined by Enlund below which austenite was preserved. The growth of the shower would therefore be interrupted and part of the ground-mass would remain as austenite (pitted martensite). In the fourth type (above 1.60 carbon) the shower was prevented and the ground-mass was entirely austenite. With increasing carbon the crystallites, which formed before the main shower, would at first be frequent and small, then coarser and less numerous as the conditions of

¹ *Carnegie Scholarship Memoirs*, 1917, vol. viii. pp. 90-92.

formation were further from the supersolubility curve, and finally they would pass over into a dendritic structure (the zigzag crystals of type IV.). At the last, when the crystals formed near the equilibrium curve, the grains would tend to be equiaxial (Fig. 22). With less rapid cooling the supersolubility curve was raised, and encountered Enlund's transition point at a higher carbon value; consequently, all the structures appeared in the same sequence but at higher carbon values. It was very commonly observed in chilled silicate melts that the crystals of a substance were bordered with a fringe of the same material. Fig. 4 (Plate XXXIV.) seemed to represent a case of that sort, the α -ferrite of troostite A being bordered with acicular martensite; the sequence would thus be troostite A, martensite needles, martensite ground-mass, and not that suggested by Mr. Whiteley, in which the needles were supposed to have been inoculated after the shower at an almost impossibly low temperature. The very important experiment in which the austenite was reconstituted on reheating hydrogen-quenched steel (2.35 carbon) at 21° C. was readily explained. For that carbon at 210° C. the conditions were very close to, and might even be above, the prolongation of the equilibrium line *aoq* for ferrite. Here, then, the growth of ferrite crystals (troostite A), so far as it could occur, would be slow and regular. The tempering of the quenched steel might operate by three independent reactions—(1) the growth of α -ferrite crystals, (2) the growth of cementite crystals, (3) the formation of a metastable solid solution (austenite), as indicated by the ferrite line (prolonged). As was indicated, white martensite and austenite were stable up to about 210° C. Now (1) was slow or even reversed, (2) was for practical purposes suspended below about 600° C., and there was left the possibility that white martensite might resolve again into austenite. That change was metastable and temporary, for the austenite would ultimately be transformed into α -ferrite by the growth of the areas of troostite A or of dendritic (type IV.) martensite. Finally, Mr. Whiteley's observations on troostite A were in direct agreement with the supersaturation diagram, in which the region of formation of that constituent was represented by a stippled area. With diminishing carbon, troostite appeared at about 1.50 carbon, and increased in quantity toward the eutectoid composition. With slower cooling it might appear at points further down the ferrite line. The observations he had made dealt with the main results recorded by Messrs. Whiteley and Enlund. The agreement between the behaviour of quenched steel and that of a supersaturated solution, especially the characteristic sequence of microstructures in martensites I. to IV., was, he believed, so close as to render quite unnecessary the revival of the theory of a metastable transition point.

CORRESPONDENCE.

Mr. WHITELEY wrote, in reply to the discussion on his paper, that Colonel Belaiew had apparently misunderstood his remarks on the distribution of the carbon in martensite. He (Mr. Whiteley) had endeavoured to show that the etching effects given by quenched steels were not due to any difference in the carbon concentration, but rather to variations in the physical condition. It was clear also that Colonel Belaiew was not in favour of the view that martensite was a solid solution. The growth of the martensite crystallites with the midrib (type IV.), to which Colonel Belaiew referred, in austenite at ordinary temperatures seemed, however, strongly to favour that view.

He (Mr. Whiteley) was much obliged to Professor Thompson for his reference to Hanemann's work, which he had unfortunately overlooked. The fact that, after tempering, the martensite crystallites contain less carbon than the matrix could not, he thought, be taken as evidence that the concentration differed originally. The extraordinary rapidity with which martensite formed at low temperatures, as shown in the experiments, seemed to make it inconceivable that any important movement of the carbon could occur during the transition. Professor Thompson's statement that a series of changes took place in α -iron when heated at low temperatures was of great interest. The effect produced in tempering type IV. martensite, described in the paper, of itself strongly suggested that the α -iron formed from martensite was somehow different from that formed from γ -iron. If facts of that kind were alone considered, he did not think that the intermediate form of iron he (Mr. Whiteley) had postulated to explain the formation of martensite could be dismissed as being altogether outside the realm of possibility.

Professor Hoyt's intimation of the appearance of a brand new idea was welcome, and aroused interest in the publication of Dr. Hanemann's forthcoming work. He (Mr. Whiteley) could not agree, however, that martensite given by a fully quenched steel containing 0.9 per cent. of carbon was structurally different from that given by steels containing from about 0.75 to 1.5 per cent. Type III. is present in all, and he very much doubted whether anyone could distinguish with certainty by examination a 0.9 carbon steel in a quenched series in which the carbon contents varied within the above limits. Neither was he quite in agreement with Professor Campbell with regard to the two troostites. In his opinion they were not absolutely different, for they undoubtedly both contained precipitated carbide in some form of α -iron.

In reply to Mr. Hallimond, he wished to say in the first place that in none of the quenching experiments was the piece allowed to float on the mercury during cooling. Invariably the liquid was kept in violent agitation until it was certain that the immersed specimen was quite cold.

Although mercury might be less effective than water as a quenching medium, yet that was counteracted in the experiments by the extremely small size of the specimens it was possible to use. Furthermore, Mr. Hallimond seemed to have missed the main argument, namely, that if γ -iron could not be retained under those conditions of quenching in certain steels containing alloying elements known to retard the transformation, the change in ordinary steels must consequently be almost instantaneous. The brief reference made in the paper to the supersaturation theory as propounded by Mr. Hallimond was entirely concerned with the appearance of ferrite areas in tempering. He thought those were not to be explained as due to the precipitation of ferrite in the labile region. That was really the point he had in mind. There could be little doubt that the formation of troostite A was very well explained by the theory, but he was not satisfied that it would account equally well for the low-temperature changes which caused the appearance of martensite. If, as Mr. Hallimond contended, martensite was simply α -iron with carbide in suspension, it would be expected that, in retarded quenching, as for example in hydrogen only, the higher the carbon content the sooner would coagulation to form troostite be evident. As far as he (Mr. Whiteley) had observed, that was not the case; the quantities of troostite M (Fig. 4) did not appear to increase in sample C with increasing carbon content. Moreover, there seemed to be no reason for the sudden halt in the formation of troostite at Ar'. If α -iron with carbide in suspension could form at 350° C. Ar'', it should surely also be able to form at higher temperatures. A gradual change from martensite to troostite A should then be revealed by sodium picrate, which was certainly not the case. His view was that the transition stage from γ -iron to α -iron, during which the martensitic solid solution appeared, was retarded by increasing carbon content as well as by alloying elements, such as manganese, nickel, and chromium.

Mr. Hallimond disputed his interpretation of Fig. 4, and stated that the dark needles bordering the troostite A were martensite. With that he (Mr. Whiteley) entirely disagreed. They were, in his opinion, undoubtedly decomposed martensite crystallites. And further, in view of the fact that troostite could form at temperatures as low as 200° C., he did not see that inoculation at about 300° C. was almost an impossibility. With regard to the apparent reformation of austenite in tempering at 210° C., he would point out that the lattice structure containing it (Figs. 23 and 35) appeared in all specimens having type III. martensite and not merely in the moderately quenched high carbon sample H. Mr. Hallimond had overlooked that fact in his explanation. A prolongation of the line *aoq* for ferrite in his diagram could not possibly approach anywhere near, say, the 1.0 per cent. carbon ordinate at 210° C.

Iron and Steel Institute.

THE EFFECT OF GRAIN UPON THE FATIGUE STRENGTH OF STEELS.

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AND

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SOME of the variations in the mechanical properties of metals that are revealed by testing them in directions that differ from the direction of rolling or forging have been known for a long time. The fibrous structure that is frequently very obviously present in rolled steel has been compared, not inaccurately, with the structure of wood, and it is not unusual to refer to steel as being tested "along the grain" and "across the grain," just as is done with timber. The variations in properties are generally well recognised by those who have to work the metals, and frequently also by those who have to inspect them, it being usual to specify the direction in which the "grain" is to lie in the test-piece that is to represent the metal. It is also well known that certain engineering specifications insist upon steel parts being so manufactured that the "grain" in the steel is disposed in specific directions with respect to the article in question.

The variation between the properties of samples of metal taken in different directions is not found in the strength but in the toughness and the ductility. There appears to be no sound evidence that the maximum stress of steel, when tested in different directions with respect to the grain, varies at all. The evidence as to the influence of the grain upon the elastic limit is vague and contradictory, except in the one respect that it indicates the influence to be very small. On the other hand, the direction of the forging or rolling grain affects very materially the values obtained for elongation, reduction of area, notched-bar test, and capacity to bend. The variations can be illustrated successfully in various ways, but they become very obvious when the ordinary routine mechanical tests are carried out upon materials orientated

in different ways with respect to the direction in which the metal has been elongated by either forging or rolling.

It is generally assumed that the variation in the properties of elongation, toughness, &c., can be referred mainly, even if not entirely, to the influence of the non-metallic materials that are incorporated in the metal. There is a good deal of evidence that this explanation is the right one. It is certainly true that where very special precautions are taken to prevent the incorporation within the metal of any undue proportion of non-metallic impurities, the resulting variation in elongation and impact found in differently oriented test-pieces is decidedly smaller than is found in those steels during the manufacture of which no such precautions have been observed.

In view of the attention that is now being paid to the fatigue strengths of engineering materials, it becomes of great importance to ascertain whether or not the relationship between the direction of the grain and the direction of the applied stresses affects the fatigue strength of a metal. In order to appreciate the importance of this matter fully, it is necessary to visualise the distribution of the grain within certain typical engineering parts. If this be done, it will be found that there are a very large number of parts subject almost solely to fatigue stresses, in which the grain is disposed in such a way that some portions of the article have to support the principal fatigue stresses that are applied in a direction parallel to the grain, whilst in other portions of the same article the stresses are disposed at right angles to the grain. Naturally, there is a still larger number of instances of parts in which the stresses are disposed at various angles between 0° and 90° with the grain.

Typical examples of forgings occur in which the main stresses in different portions will be distributed variously in relation to the grain, as, for example, a crankshaft or a gear-wheel. Evidently it is important to know whether this variation in the grain affects the real strength of the parts when they are exposed to fatigue stresses.

Another point which is of some interest is the possibility that the direction which a fatigue crack follows in an engineering part is influenced by the distribution of the grain of the steel. It is exceedingly difficult in practice to know whether the direction of a fracture has been influenced by this factor, because it is not at

all easy to appreciate the precise direction in which the stresses have been applied, and therefore to connect the direction of the fracture with the direction of the stresses. This matter has also received some consideration in so far as is possible with the simple type of specimen used in the Wöhler test.

For the purposes of the investigation, a considerable number of materials have been examined. The main series of tests has been made upon a sample of steel which has been investigated in the ingot and then through the various stages of forging, a known reduction in cross-section being made at each step. At each stage of the reduction, the material has been tested on specimens cut parallel to the grain and also at right angles to the grain. Besides the fatigue tests (which have been carried out by the Wöhler method), comparative tensile tests and impact tests have been made, whilst a record has been kept of the macrostructure and the microstructure of the material. In addition to this leading series of tests other materials have been examined which are of a more obviously commercial nature. In particular, the examination has included rolled boiler plate, a forged bar of high-class nickel chrome steel, Armco iron, and two varieties of ordinary Staffordshire wrought iron. All these materials have been submitted to the same process of investigation.

The first set of materials employed in the investigation consisted of two steel slabs supplied by the Royal Aircraft Establishment, Farnborough. One of these was a slab of plain carbon steel, and the other was of nickel chromium steel. The chemical compositions of the two materials were as follows :

	Slab A.	Slab B.
Carbon	0·34	0·28
Silicon	0·13	0·20
Manganese	0·79	0·61
Sulphur	0·063	0·044
Phosphorus	0·046	0·038
Nickel	0·15	3·55
Chromium	0·22	0·94

The slabs were supplied in the size 36 in. \times 3 in. \times 1 in., and therefore unfortunately were not suitable for the preparation of transverse Wöhler specimens. As a result, it was only possible to make tensile and impact tests in the transverse direction. Before any tests were made, a number of specimens were prepared 1 inch square and 3 inches long. The specimens thus

prepared from steel A were normalised at 840°C. , whilst those prepared from steel B were hardened in oil from 830°C. and then tempered at 650°C. , followed by quenching in water. The plain carbon steel A endured the normalising treatment quite satisfactorily, but the specimens of the nickel chrome steel B split during heat treatment. A duplicate set of specimens was made, and again the steel cracked on treatment. Further work on this particular slab was therefore abandoned.

The specimens from the slabs were cut in three directions—namely, parallel to the length of the slab, parallel to the width of the slab, and at an angle of 45° with the other two directions. Two tensile and two notched-bar tests were made on specimens cut in each of these three directions. The results obtained from slab A were as follows :

	AL.1.	AL.2.	AT.1.	AT.2.	AO.3.	AO.4.
Direction of grain	Longi- tudinal	Longi- tudinal	Trans- verse	Trans- verse	Oblique	Oblique
Elastic limit (tons per square inch)	22.6	23.4	23.2	23.5	23.0	23.1
Yield point (tons per square inch)	24.3	26.1	26.5	27.1	25.6	26.4
Maximum stress (tons per square inch)	43.2	43.6	42.6	42.7	42.9	42.1
Elongation per cent.	26.4	26.1	22.6	21.8	25.8	26.7
Reduction of area per cent.	52.1	51.9	43.2	41.1	47.8	52.2
Izod value (ft.-lbs.)	35	34	13	14	16	15

This series of tests is of considerable interest, and it was unfortunate that the size of the slab made it impossible to follow up the results by determinations of the fatigue range of the steel on specimens cut in the various directions. In particular, these test results show that the elastic limit, yield point, and maximum stress are, to all intents and purposes, entirely unaffected by the orientation of the grain in the test specimens. There is not so much variation as might be expected in the values for the elongation and the reduction of area per cent. given by the specimens cut in the different directions. The values from the transverse specimens are certainly lower than those from the specimens cut

in the other directions, but the difference is not very great. The most remarkable test results are the notched-bar values. These show clearly the influence of the longitudinal grain upon the toughness value recorded by the material. The results also show that although the specimens obliquely cut are not appreciably lower in ductility than those with a longitudinal grain, they are distinctly lower in toughness, which is a matter of considerable interest.

It was considered to be of importance that the influence of the grain should be studied upon material in which the production of the grain could be carefully watched and controlled. This made it necessary to commence experiments with unforged steel. It was similarly desirable to determine directly the properties of the unforged material, and therefore to obtain a value for the fatigue strength of steel in the ingot form. This value would provide a suitable criterion for the effect of the forging grain. It was considered very desirable, however, to make a very careful selection of the cast steel. It would have been quite possible to obtain the steel required for the forging experiments by taking the complete cross-section of an ingot. This procedure would, however, have involved the possible employment of steel of decidedly heterogeneous characteristics. It would have been almost impossible by this method to avoid the use of material which consisted of a mixture of columnar and equiaxial crystals. This mixture of different types of crystal might very possibly have had a serious effect upon the fatigue values. To avoid encountering this difficulty, it was decided to obtain material which would be crystallographically as homogeneous as possible, and would consist entirely of equiaxial crystals. The material which was employed, therefore, was trepanned from a large ingot. The ingot employed was an octagonal one of approximately 28 inches diameter, and from it the centre was removed. The portion employed was taken from the lower part of the ingot. The material which was extracted in this way consisted entirely of equiaxial crystals. It had a diameter of $13\frac{1}{2}$ inches as extracted. A reproduction of the macro etching of the complete cross-section of this portion of the material is shown in Fig. 1 (Plate XL.). A sulphur print taken on the cross-section indicated clearly that the material was satisfactorily homogeneous and free from any piping or undue segregation at the

centre of the ingot. Also the macro etching shows the material to be crystallographically homogeneous throughout.

The chemical composition of the steel in the trepanned cylinder was as follows :

	Per Cent.
Carbon	0.28
Silicon	0.15
Manganese	0.69
Sulphur	0.025
Phosphorus	0.032
Nickel	0.16
Chromium	nil

For the tests on the steel in the as cast condition specimens were cut in two directions, called respectively longitudinal and transverse. The longitudinal specimens were cut in a direction parallel with the major axis of the ingot, and the transverse specimens were cut at right angles to this axis. The macro-structures of the longitudinal and transverse sections given in Fig. 2 indicates that there is no variation in the different directions in the casting so far as crystalline distribution and orientation is concerned, and therefore the properties of longitudinal and transverse specimens should be identical. (See Plate XL.)

The test specimens that were extracted from the cylinder were cut to 1 inch square and were then normalised by heating at 850° C. Figs. 3 and 4 (Plates XL. and XLI.) show the microstructure of the material as displayed respectively on longitudinal and transverse sections after normalising. No further treatment was given to the materials before testing. The results of the tensile and notched-bar tests taken from the cast material are as follows :

	Longitudinal.	Transverse.
Number of specimen	FL.8	FT.8
Elastic limit (tons per square inch)	16.4	16.3
Yield point (tons per square inch)	20.3	20.4
Maximum stress (tons per square inch)	38.3	38.9
Elongation per cent.	19.7	18.2
Reduction of area per cent.	25.8	23.6
Number of specimen	FL.9	FT.9
Izod value (ft.-lbs.)	16.7	17.0

These tests require no particular consideration. It is considered that the notched-bar values are, if anything, on the high side for material of this type, as cast and normalised. As is usual in material of this kind, the reduction of area percentage is rather low. As was expected, there is no difference in mechanical pro-

perties between the specimens cut in the two directions from the casting.

From the trepanned casting a sample of the following dimensions, $13\frac{1}{2}$ inches diameter by $7\frac{1}{2}$ inches thick, was cut out and forged into a billet 30 inches long by 12 inches wide by 3 inches thick. This corresponds to a reduction in cross-sectional area of 75 per cent. from the casting. Macrosections were prepared from the resulting forged slab in both longitudinal and transverse directions, and the structures as developed are shown in Fig. 5. It is evident that quite a decent amount of longitudinal grain has been developed in the material. As might be expected from the form of the forging, the material also shows a certain amount of transverse grain. (See Plate XLI.)

The materials for the mechanical tests were cut out in directions parallel to the length and the width of the slab, and were machined to 1 inch square section. All the specimens were then normalised at a temperature of 850° C. From two of the specimens microsections were prepared, the resulting longitudinal and transverse structures being shown in Figs. 6 and 7 (Plate XLI.).

The tensile and notched-bar tests made in both directions gave the following results :

	Longitudinal.	Transverse.
Number of specimen	CL.1	CT.1
Elastic limit (tons per square inch)	20.2	19.6
Yield point (tons per square inch)	21.2	21.5
Maximum stress (tons per square inch)	36.4	36.5
Elongation per cent.	30.8	29.0
Reduction of area per cent.	57.4	48.4
Number of specimen	CL.2	CT.2
Izod value (ft.-lbs.)	34.0	27.3

The tests show that the "strength" properties of the material are the same both longitudinally and transversely, but that the ductility and toughness of the material is somewhat less in the transverse than in the longitudinal direction.

From the billet, the forging of which has just been described, a portion 8 inches long by 12 inches wide by 3 inches thick was cut out and forged down to a slab 16 inches long by 6 inches wide by 3 inches thick. The material was drawn out so that the 8-inch length of the first billet became the 16-inch length of the second billet, and therefore so that the elongation of the steel was in the direction of the grain produced in the first forging

operation. The second forging operation resulted in a reduction of cross-sectional area of 50 per cent. from one billet to another, the total reduction of area from the cast slab to the second billet being 87.5 per cent. The resulting slab was examined macroscopically and microscopically, the macrostructures and microstructures obtained being shown in Figs. 8, 9, and 10. The macro photographs show that the grain has become decidedly more pronounced in the longitudinal direction, but that the grain in the transverse direction does not show any very marked difference as compared with that of the first billet. (See Plates XLI. and XLII.)

The specimens for testing were cut to 1 inch square, and were normalised at a temperature of 850° C. The results obtained in the tensile and notched-bar tests were as follows :

	Longitudinal.	Transverse.
Number of specimen	DL.8	DT.8
Elastic limit (tons per square inch)	20.8	20.8
Yield point (tons per square inch)	21.2	21.2
Maximum stress (tons per square inch)	35.5	35.6
Elongation per cent.	33.4	22.2
Reduction of area per cent.	58.3	23.8
Number of specimen	DL.9	DT.9
Izod value (ft.-lbs.)	61.7	30.0

These test results show very clearly the difference in ductility and toughness between the longitudinal and transverse specimens. The reduction of area value shows in a very marked manner, and the impact value almost equally well, how inferior the transverse specimens are to those taken in a longitudinal direction.

Samples from this same slab were hardened and tempered. This operation was carried out with the intention of noting whether the effect of the grain was any more apparent in quenched and tempered than in normalised material, in view of the difference in the microstructure. Specimens 1 inch square were therefore hardened in oil from a temperature of 850° C. and thereafter tempered at 640° C. for thirty minutes. Figs. 11 and 12 (Plate XLII.) show the microstructures of the longitudinal and transverse sections taken from the hardened and tempered bars. The results obtained from the tensile and notched-bar tests made on these specimens are as given below.

The test results show that the deficiency in toughness of the transverse as against the longitudinal material is greater in the

hardened and tempered steel than in the normalised steel. In other respects there is not very much difference between the properties of the two types of material.

	Longitudinal.	Transverse.
Number of specimen	DDL.18	DDT.18
Elastic limit (tons per square inch)	24.5	25.3
Yield point (tons per square inch)	25.7	25.7
Maximum stress (tons per square inch)	40.5	40.2
Elongation per cent.	29.8	21.2
Reduction of area per cent.	66.9	38.2
Number of specimen	DDL.19	DDT.19
Izod value (ft.-lbs.)	59.0	16.3

From the same billet (C) that provided the material for forging into the slab which provided the specimens for series D, a further portion measuring 4 inches by 12 inches by 3 inches was forged to a plate 24 inches by 6 inches by 1 inch. The forging was done in such a way that the 4-inch length became the 24-inch length, and therefore so that the grain of the original slab was elongated still further. This amount of forging corresponded to a reduction of section 83.3 per cent. between the two slabs, and a total reduction of cross-sectional area of 96 per cent. between the original casting and the final slab. The macrostructure of the resulting material was examined on both transverse and longitudinal sections, and the structures revealed are shown in Fig. 13 (Plate XLII.); while Figs. 14 and 15 (Plate XLII.) represent the microstructures of the material on longitudinal and transverse sections of 1 inch square specimens after normalising at a temperature of 850° C. It is evident that there is some microscopic evidence of flow in a transverse direction.

The results of the tensile and notched-bar tests made upon the material in this final slab are as follows :

	Longitudinal.	Transverse.
Number of specimen	EL.8	ET.8
Elastic limit (tons per square inch)	20.1	18.9
Yield point (tons per square inch)	20.6	19.3
Maximum stress (tons per square inch)	36.0	36.0
Elongation per cent.	33.1	28.5
Reduction of area per cent.	58.7	43.5
Number of specimen	EL.9	ET.9
Izod value (ft.-lbs.)	74.0	29.0

There is not so much discrepancy between the values for elongation and reduction of area obtained on the transverse and the longitudinal specimens, but the transverse specimen is still more deficient in notched-bar value as compared with the

longitudinal specimen than is found in the results from any of the previous slabs.

The mechanical tests obtained upon this basic experimental material in the various stages of its working can be usefully summarised, so that the variation in properties produced by the forging can be observed. The collected results are as follows :

Longitudinal Specimens.

	Casting (Normal- ised).	First Forging (Normal- ised).	Second Forging (Normal- ised).	Second Forging (Hardened and Tem- pered).	Third Forging (Normal- ised).
Elastic limit (tons per square inch) .	16.4	20.2	20.8	24.5	20.1
Yield point (tons per square inch) .	20.3	21.2	21.2	25.7	20.6
Maximum stress (tons per square inch)	38.3	36.4	35.5	40.5	36.0
Elongation per cent.	19.7	30.8	33.4	29.8	33.1
Reduction of area per cent. . . .	25.8	57.4	58.3	66.9	58.7
Izod value (ft.-lbs.)	16.7	34.0	61.7	59.0	74.0

Transverse Specimens.

	Casting (Normal- ised).	First Forging (Normal- ised).	Second Forging (Normal- ised).	Second Forging (Hardened and Tem- pered).	Third Forging (Normal- ised).
Elastic limit (tons per square inch) .	16.3	19.6	20.8	25.3	18.9
Yield point (tons per square inch) .	20.4	21.5	21.2	25.7	19.3
Maximum stress (tons per square inch)	38.9	36.5	35.6	40.2	36.0
Elongation per cent.	18.2	29.0	22.2	21.2	28.5
Reduction of area per cent. . . .	23.6	48.4	23.8	38.2	43.5
Izod value (ft.-lbs.)	17.0	27.3	30.0	16.3	29.0

The most obvious points of interest in regard to these results are, first, the remarkable uniformity in the values for elastic limit, yield point, and maximum stress; secondly, the increasing discrepancy between the Izod value obtained from the longitudinal and the transverse specimens; and, thirdly, the regular increase in the notched-bar value in the longitudinal specimens as the forging progresses in amount.

The fatigue tests on all the specimens were made by the same methods. The Wöhler type of loading was employed throughout,

and the fatigue values have been obtained by the direct endurance method. Each set of fatigue specimens was taken from 1 inch square samples, which were heat-treated along with the material employed for the tensile and notched-bar tests reported above. Besides the values obtained by the endurance method, determinations have been made in all cases by the method developed by Gough in which a load/deflection curve is taken of the rotating specimen. The only difference that has been introduced into Gough's method in the present tests is that whereas Gough measures the deflection of the specimen by means of an optical lever, the deflections of the present specimens have been measured directly. The steelyard arm of the testing machine has been employed for these measurements, the deflection of the end of the arm farthest from the test-piece being multiplied by suitable levers and then measured by means of a travelling microscope. It was found that this method gave entirely satisfactory results. The values obtained by the endurance and the deflection methods from the series of specimens already described are as follows :

Endurance Method.

Material.	Longitudinal.	Transverse.
Cast (normalised)	$\pm 13\cdot0$	$\pm 12\cdot6$
First forging (normalised)	$\pm 16\cdot2$	$\pm 15\cdot0$
Second forging (normalised)	$\pm 16\cdot2$	$\pm 13\cdot5$
Second forging (hardened and tempered)	$\pm 19\cdot5$	$\pm 17\cdot0$
Third forging (normalised)	$\pm 16\cdot0$	$\pm 15\cdot5$

Deflection Method.

Material.	Longitudinal.	Transverse.
Cast (normalised)	$\pm 12\cdot0$	$\pm 11\cdot5$
First forging (normalised)	$\pm 16\cdot2$	$\pm 15\cdot4$
Second forging (normalised)	$\pm 16\cdot0$	$\pm 13\cdot1$
Second forging (hardened and tempered)	$\pm 18\cdot9$	$\pm 18\cdot0$
Third forging (normalised)	$\pm 16\cdot4$	$\pm 15\cdot0$

The figures quoted above show that the endurance method and the deflection method give substantially similar results.

This is generally entirely true of the longitudinal specimens, but it is necessary to explain that the exact values obtained by the deflection method on the transverse specimens are a little doubtful. It was found throughout the investigation that whereas with the longitudinal specimens the change of slope of the load/deflection curve gave quite a satisfactory indication of the fatigue strength as determined by the endurance method, this was not always the case with the transverse specimens. It was very difficult by the deflection method to obtain anything like consistent results from the transverse specimens. Some specimens would give distinctly higher results than others, and there seemed to be no certainty about the behaviour of the specimens cut perpendicular to the grain. Repeat determinations on the same specimens gave entirely incomprehensible results. There was no such difficulty with the longitudinal specimens, so that the fault cannot be put down to the apparatus or the method of measuring the deflection, and it appears from all the tests, both endurance and deflection, that have been made that the transverse specimens may be expected to behave in this way. The values of fatigue strength that have been quoted in the tables above are the ones which appear to be the most satisfactory. They are approximately the mean values obtained in the various repeat determinations by the deflection method.

By the endurance method the transverse specimens gave more consistent results than were obtained by the deflection method. Even so, however, there was a distinct tendency to a variation amongst the specimens, and it was necessary to break a considerably larger number of transverse than of longitudinal specimens in order to arrive at a reasonable value of the fatigue strength of the material.

The general trend of the results is definitely to show that there is not a very large difference between the fatigue strengths of specimens taken parallel to, and at right angles to, the grain of the material, but that in all instances the difference is in favour of the longitudinal material. The discrepancy between the longitudinal and transverse fatigue strengths was not so great as has been suggested. In view, however, of the irregularity of the behaviour of the transverse specimens, it is quite easy to believe that decidedly lower values than those indicated by these tests

would be obtained from some of the materials stressed at right angles to the grain. It would certainly be the safest thing to assume that the values given above indicate the minimum difference that is likely to be found between longitudinal and transverse materials, and that a much greater discrepancy may arise in many instances, the discrepancy being created by a greater deficiency in the transverse specimens.

It is also worthy of notice that even the transverse specimens have a kind of "longitudinal" grain. Instead of the fibres of the steel that compose the grain being cylindrical threads, they appear to be more or less flat and of the nature of ribbons. The most perfect transverse sections of the expected type would have been those taken at right angles to both the directions that were actually tested. In the actual production of the right grain in this direction, however, the steel would have been reduced by the forging to such a dimension that the extraction of a useful size of serviceable fatigue test-piece would have become quite impossible. It is at any rate just conceivable that a specimen cut in the most "transverse" direction would have given still lower results than the specimens taken herein as transverse, and which in fact are transverse in the ordinary commercial acceptance of the term.

The first two materials of a definitely commercial nature that were tested consisted of first a portion of boiler plate, and second a forged slab of nickel chrome steel made in accordance with the Air Ministry's specification K.1. The samples of rolled boiler plate that were tested had dimensions of 36 inches by 7 inches by $1\frac{1}{4}$ inch, and it was understood that the greatest dimension of the test specimen was parallel to the length of the plate from which it was selected. The chemical composition of the material used was as follows :

	Per Cent.
Carbon	0.23
Silicon	0.06
Manganese	1.12
Sulphur	0.028
Phosphorus	0.059
Nickel	0.15
Chromium	nil

The material was delivered in the condition in which it would normally be used, and therefore no further heat treatment was

given to the metal prior to testing. The test specimens were cut parallel to, and at right angles to, the length of the slab. Both macroscopic and microscopic examinations were made on sections of the metal taken in both directions. Fig. 16 (Plate XLIII.) shows the macrostructures of the longitudinal and transverse sections of the metal. These sections indicate that the material has been worked quite thoroughly. It is evident that the material shows a decided longitudinal flow, together with a certain amount of transverse flow. The photomicrographs shown in Figs. 17 and 18 indicate that there is a certain difference between the specimens cut in the two directions. In the longitudinal section the direction of the included slag streaks is quite plain, showing fairly clearly that the material has been drawn out in this direction more than in the other, this feature being absent from the transverse section. The whole structure of the material is that of a fairly fine-grained normalised steel.

Tensile and notched-bar tests were carried out upon the steel in the longitudinal and transverse directions, the results that were obtained being as follows :

	Longitudinal.	Transverse.
Number of specimen	GL.8	GT.8
Elastic limit (tons per square inch)	19.6	15.2
Yield point (tons per square inch)	21.0	20.1
Maximum stress (tons per square inch)	35.5	35.6
Elongation per cent.	33.0	32.8
Reduction of area per cent.	61.2	55.9
Number of specimen	GL.9	GT.9
Izod value (ft.-lbs.)	70.7	48.0

As has also been noticed in connection with the previous series of forged specimens, the greatest difference in properties between the longitudinal and transverse sections is shown by the notched-bar test. The other mechanical tests on the material do not show any very marked differences.

The fatigue tests were carried out as before on the Wöhler machine by the endurance and deflection methods. The results obtained were as follows :

	Endurance Method.	Deflection Method.
Longitudinal specimen	± 17.2	± 17.0
Transverse specimen	± 17.4	± 17.0

These tests show that there is no noticeable difference in the fatigue properties of the material in directions parallel to, and

at right angles to, the grain of the slab. This result is somewhat in keeping with the expectations raised by the macroscopic examination of the material.

It was thought that specimens cut at an angle of 45° to the length of the slab might show some difference in mechanical properties as compared with the longitudinal and transverse specimens previously examined. Such a possibility exists, in view of the method by which boiler plate is produced. Specimens therefore were cut at 45° with the length of the slab and tested for tensile and notched-bar properties. The results obtained were as follows :

Number of specimen	GO.1
Elastic limit (tons per square inch)	20.9
Yield point (tons per square inch)	21.9
Maximum stress (tons per square inch)	36.0
Elongation per cent.	33.1
Reduction of area per cent.	59.1
Number of specimen	GO.2
Izod value (ft.-lbs.)	50.7

It is evident that the mechanical properties of the specimens cut in this direction do not vary appreciably from those of the specimens cut transversely. Under the circumstances no fatigue tests were carried out.

The nickel chromium steel slab, which was made to comply with the Air Ministry's specification K.1, had the following chemical composition :

	Per Cent.
Carbon	0.39
Silicon	0.26
Manganese	0.47
Sulphur	0.027
Phosphorus	0.030
Nickel	3.53
Chromium	0.63

The material was cast in an ingot having a cross-section of 17 inches by 15 inches, which weighed 35 cwt. This was brought down in the blooming-mill to a finished section of 12 inches by $7\frac{1}{2}$ inches. After discarding from the top and the bottom, a billet approximately 8 feet long was left, and from this billet the section used in the present investigation was cut. Before parting off the section used, the billet was planed to 11 inches by $6\frac{1}{2}$ inches, and the

section cut out was then forged to provide a slab 37 inches by 7 inches by $1\frac{1}{4}$ inch.

The specimens for the mechanical tests were cut out in the longitudinal and transverse directions and measured 1 inch by $1\frac{1}{4}$ inch. The various specimens were then heat-treated as follows :

Hardened in oil from 830° C.

Tempered at 675° C. for thirty minutes and quenched in water.

On specimens that had been treated in this way an examination was made of the macrostructure and the microstructure. The results of the macroscopic examination are shown in Fig. 19. It is evident that the material has developed a certain amount of transverse flow as well as longitudinal flow. The microstructures of the material are quite normal for this class of metal, and are shown in Figs. 20 and 21 (Plate XLIII.).

Tensile and notched-bar tests were carried out upon transverse and longitudinal specimens in the usual way, the results obtained being as follows :

	Longitudinal.	Transverse.
Number of specimen	HL8	HT8
Elastic limit (tons per square inch) . .	42·8	27·4
Proof stress (tons per square inch) . .	53·9	36·3
Maximum stress (tons per square inch) .	64·8	65·8
Elongation per cent.	20·6	19·6
Reduction of area per cent.	61·0	35·7
Number of specimen	HL9	HT9
Izod value (ft.-lbs.)	57·0	18·0

It is interesting to observe that on this material there is a distinct difference between the elastic properties of the metal when tested in the two directions. The transverse and longitudinal specimens of the plain carbon steels did not vary in elastic limit and yield point. The nickel chrome steel, however, does show a marked difference in these properties. There is a very decided variation also between the values for the reduction of area and the toughness of the specimens selected in the two directions. As before, the notched-bar test shows up this difference rather more completely than does anything else.

The fatigue tests were carried out exactly as before and gave the following results :

	Endurance Method.	Deflection Method.
Longitudinal specimen	± 31·8	± 32·0
Transverse specimen	± 29·6	± 29·0

It is interesting to note that once again there is no very marked difference between the fatigue properties of the metal tested in the two directions.

The next material that was worked upon was Armco iron. This material was purchased in the form of a forged slab, having the dimensions 36 inches by 7 inches by 1 inch. The chemical composition of the material was as follows :

	Per Cent.
Carbon	0.01
Silicon	0.01
Manganese	0.05
Sulphur	trace
Phosphorus	0.010

The material was not used in the condition as received, but all the specimens were normalised at a temperature of 960° C. before testing and before making the microscopical examination. The material was examined macroscopically, and Fig. 22 (Plate XLIV.) shows the structures of the longitudinal and transverse sections. The results of the microscopical examination of the material are shown in Figs. 23 and 24, these having been made upon specimens that have been normalised, as described.

The specimens for all the mechanical tests were extracted in the form of 1 inch square bars, and these were normalised before testing. The results obtained in the tensile and notched-bar tests were as follows :

	Longitudinal.	Transverse.
Number of specimen	ML.8	MT.8
Elastic limit (tons per square inch)	11.9	11.7
Yield point (tons per square inch)	13.1	14.7
Maximum stress (tons per square inch)	21.4	22.8
Elongation per cent.	48.5	43.5
Reduction of area per cent.	80.3	67.8
Number of specimen	ML.9	MT.9
Izod value (ft.-lbs.)	90.0	56.3

The mechanical tests show that there is a distinct difference in toughness between the longitudinal and the transverse specimens. The results for reduction of area also indicate some measure of difference in the properties of the material in the two directions.

The specimens for the fatigue tests were normalised as described, and the results obtained upon the specimens in the two directions are as follows :

	Endurance Method.	Deflection Method.
Longitudinal specimen	± 11.8	± 11.5
Transverse specimen	± 11.8	± 11.0

The various materials whose properties have been obtained so far are those in which there is not likely to be any very marked or unduly large development of slag. As a result, therefore, it is not so probable that the properties of the longitudinal and transverse specimens of the material will be differentiated so markedly as would occur if the steel contained a large proportion of non-metallic impurities. Under the circumstances, therefore, it was decided to make some tests upon forged wrought iron of a common quality. The material employed was ordinary South Staffordshire wrought iron, and two separate samples were obtained. One of the specimens was more phosphoric than the other.

The first slab that was investigated had the dimensions 36 inches by $6\frac{1}{2}$ inches by 1 inch. The iron had been forged to these dimensions in the ordinary way. The chemical composition of the material in the slab was as follows :

	Per Cent.
Carbon	0.03
Silicon	0.04
Manganese	0.02
Sulphur	trace
Phosphorus	0.068

The material was examined macroscopically, and the results are shown in Fig. 25 (Plate XLIV.). It is evident that the material has a very well-marked flow in the longitudinal direction, and is very thoroughly split up by longitudinal slag streaks. Examined in the transverse direction, however, the iron appears also to have a certain amount of flow. This no doubt is due to the way in which the material has been forged out, causing the slag to be distributed in flattish plates in between the layers of metal. The slag is sufficiently plentiful to run, not in fibres, but rather in ribbons. The material is very clearly folded on the transverse section examined.

A microscopical examination of the material was also made, and is shown in Figs. 26 and 27 (Plates XLIV. and XLV.). The longitudinal section shows the way in which the slag runs in parallel streaks. The transverse section gives some indication of the ribbon effect indicated by the macroscopic examination. The macrostructures and microstructures are fairly typical of wrought iron.

In order to make the tests comparable with those carried out on Armco iron, the specimens for all the mechanical tests were

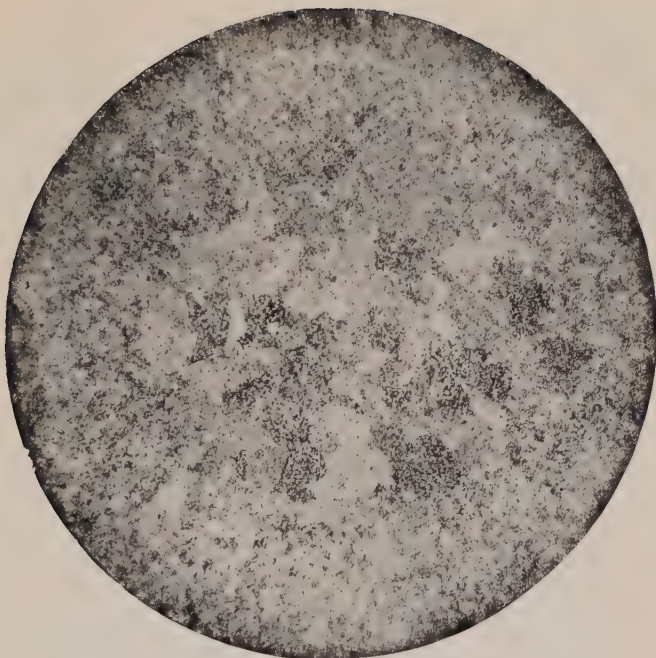


FIG. 1.—Quarter size

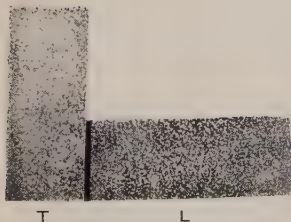


FIG. 2.—One-third actual size.

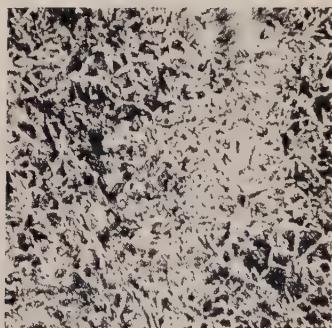


FIG. 3.— $\times 50$.
(Longitudinal.)

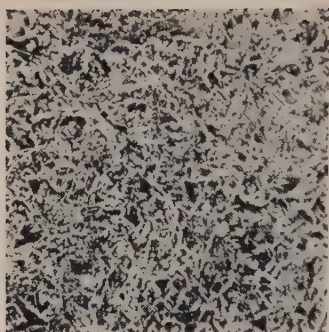


FIG. 4.— $\times 50$.
(Transverse.)

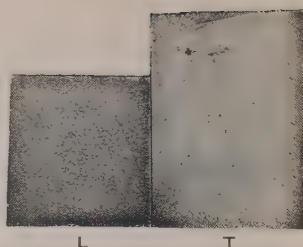


FIG. 5.—One-quarter actual size.



FIG. 6.— $\times 50$.
(Longitudinal.)

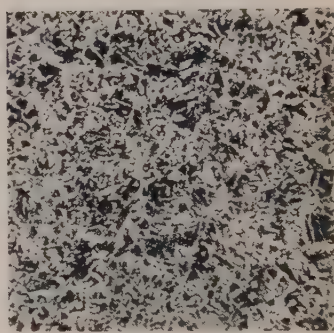


FIG. 7.— $\times 50$.
(Transverse.)



FIG. 8.—One-third actual size.

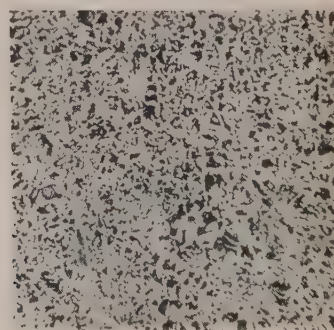


FIG. 9.— $\times 50$ ¹
(Longitudinal.)

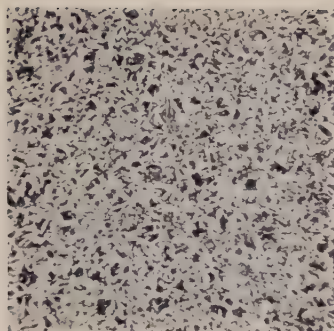


FIG. 10.— $\times 50$.
(Transverse.)

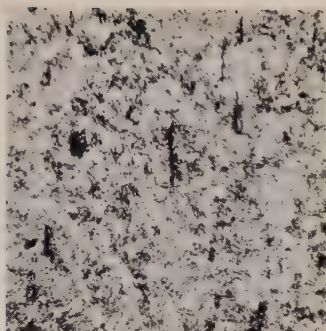


FIG. 11.— $\times 50$.
(Longitudinal.)

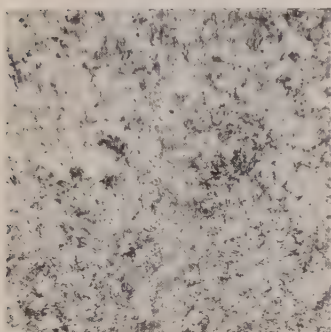


FIG. 12.— $\times 50$.
(Transverse.)

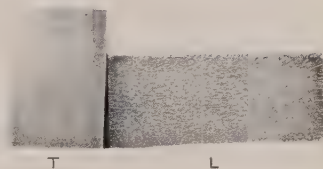


FIG. 13.—One-third actual size.

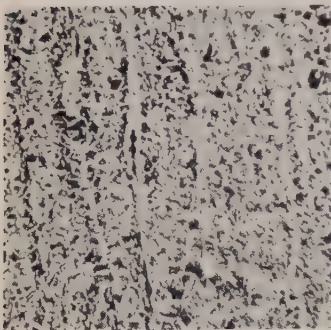


FIG. 14.— $\times 50$.
(Longitudinal.)

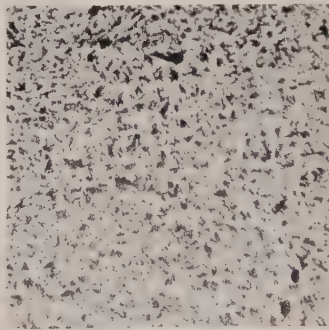


FIG. 15.— $\times 50$.
(Transverse.)

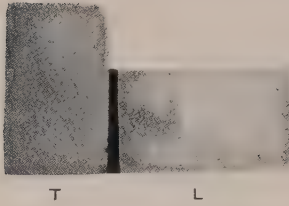


FIG. 16.—One-third actual size.

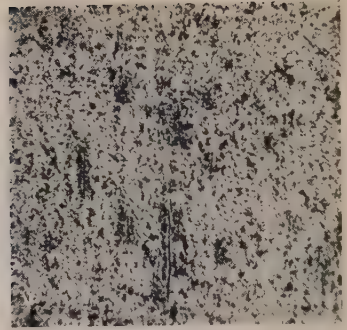


FIG. 17.— $\times 50$.
(Longitudinal.)

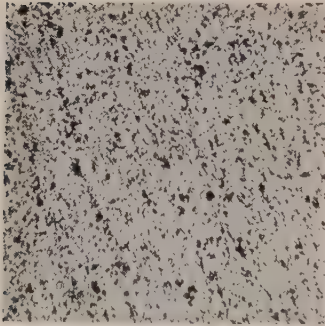


FIG. 18.— $\times 50$.
(Transverse.)

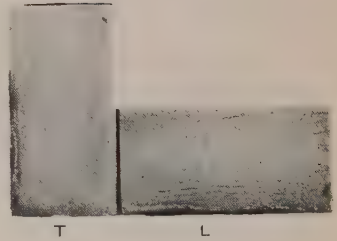


FIG. 19.—One-third actual size.

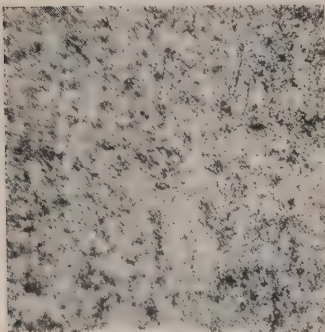


FIG. 20.— $\times 50$.
(Longitudinal.)

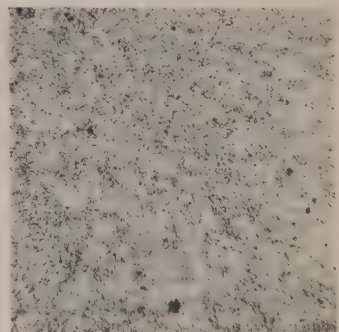


FIG. 21.— $\times 50$.
(Transverse.)



FIG. 22.—One-third actual size.

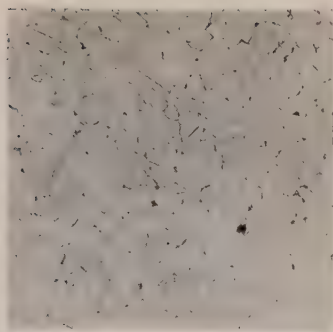


FIG. 23.— $\times 50$.
(Longitudinal.)

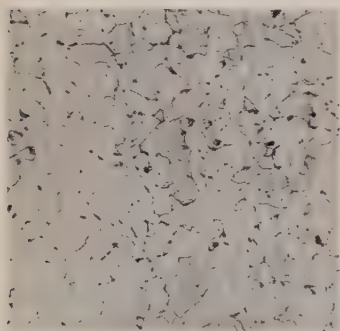


FIG. 24.— $\times 50$.
(Transverse.)

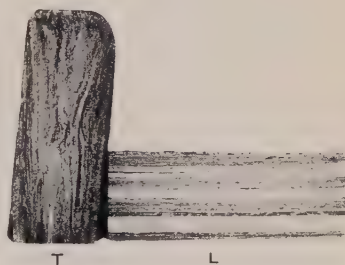


FIG. 25.—One-third actual size.



FIG. 26.— $\times 50$.
(Longitudinal.)

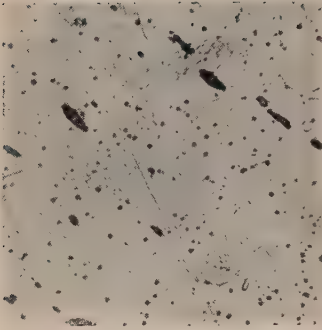


FIG. 27.— $\times 50$.
(Transverse.)

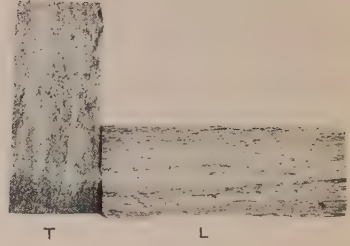


FIG. 28.—One-third actual size.

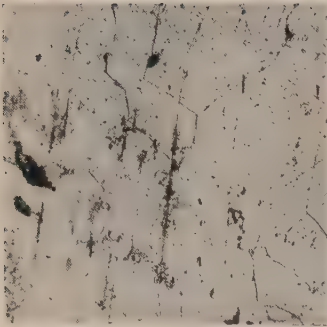


FIG. 29.— $\times 50$.
(Longitudinal.)

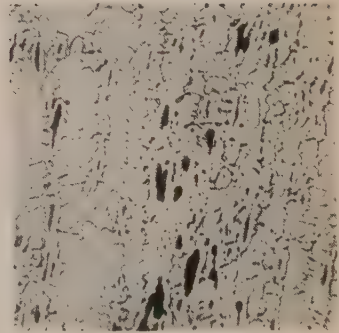


FIG. 30.— $\times 50$.
(Transverse.)

normalised at a temperature of 960° C. before testing. The results of the tensile and notched-bar tests made upon the material were as follows :

	Longitudinal.	Transverse.
Number of specimen	JL.8	JT.8
Elastic limit (tons per square inch)	10.1	9.7
Yield point (tons per square inch)	13.7	11.7
Maximum stress (tons per square inch)	24.4	20.9
Elongation per cent.	31.2	12.6
Reduction of area per cent.	38.6	27.1
Number of specimen	JL.9	JT.9
Izod value (ft.-lbs.)	51.3	33.0

In making the tensile test it was difficult to obtain satisfactory results, in consequence of the liability of the material to split longitudinally. This was particularly evident when testing the specimens cut out in the transverse direction. It was quite usual for such tensile test-pieces to split down the middle during the period of testing, and then for one-half of the split test-piece to fracture completely before the other half.

The fatigue tests were carried out on specimens that had been normalised at 960° C. in the form of 1 inch square bars. The tests were carried out both by the endurance and by the deflection method. It was very difficult indeed to obtain satisfactory results by either method. A large number of test-pieces were broken, and the results obtained were distinctly erratic. The indications given by the deflection method were by no means regular, and the results given below show the most representative value that can be extracted from the numerous tests made. During the running of the endurance specimens, both longitudinal and transverse, it was observed frequently that the specimen did not break in the ordinary way, but commenced to split longitudinally along the parallel. This of course led to the eventual fracture of the specimen, but not by the ordinary methods. The most satisfactory results that can be given for the fatigue strength of the material in the different directions are as follows :

	Endurance Method.	Deflection Method.
Longitudinal specimen	± 10.0	± 9.8
Transverse specimen	± 9.5	± 9.2

The other wrought iron slab, which was also obtained to the dimensions 36 inches by 6½ inches by 1 inch, had the following chemical composition :

	Per Cent.
Carbon	0.02
Silicon	0.15
Manganese	0.06
Sulphur	trace
Phosphorus	0.273

Fig. 28 (Plate XLV.) shows the results of the macroscopical examination of the sections. The longitudinal arrangement of the material is not very different from that of the previous specimen. Similarly, in the transverse sections there is distinct evidence of some transverse flow due to the same cause as before. The microstructures of the material were extracted from specimens which had been normalised at temperatures of 960°C . Figs. 29 and 30 (Plate XLV.) show these structures. They show that the slag in this particular sample is somewhat less massive and more uniformly distributed than that in the previous slab. There is clear evidence again of the way in which the slag has been flattened out into ribbons and not into fibres.

The specimens for the mechanical tests were normalised at a temperature of 960°C . before any tests were made. The specimens at the time of normalising were 1 inch square bars. The results obtained in the tensile and notched-bar tests on the materials were as follows :

	Longitudinal.	Transverse.
Number of specimen	KL.8	KT.8
Elastic limit (tons per square inch)	11.5	10.5
Yield point (tons per square inch)	13.8	13.5
Maximum stress (tons per square inch)	22.6	15.4
Elongation per cent.	12.1	3.0
Reduction of area per cent.	18.5	3.9
Number of specimen	KL.9	KT.9
Izod value (ft.-lbs.)	10.3	7.3

There is a very marked difference in mechanical properties between the longitudinal and transverse specimens, this difference extending to the maximum stress of the material. This difference is sufficiently great to be interesting, but is not unexpected in view of the nature of the material.

In making the fatigue tests on this slab there was not so much trouble with the longitudinal splitting of the specimens. This can be understood from the microstructure of the material. The results, however, were again very irregular, and it was difficult to obtain any very satisfactory value from the material. The

most representative results to be obtained from the observations were as follows :

	Endurance Method.	Deflection Method.
Longitudinal specimen . . .	$\pm 10\cdot2$	$\pm 10\cdot3$
Transverse specimen . . .	$\pm 10\cdot0$	$\pm 9\cdot6$

The results of the examination of the mechanical properties of the various materials are not entirely comprehensible unless careful consideration is given to the way in which the test specimens have fractured. The tensile fractures given by all the materials were more or less normal. The longitudinal test-pieces from the forged specimens gave, as a rule, cup and cone fractures, whilst the transverse specimens generally produced a fairly flat fracture, although in some of them in which the ductility was comparatively high the fracture was of the semi-cup and cone variety. The material tested as cast had but a fairly low ductility, and the fractured tensile specimens, both longitudinal and transverse, showed no signs at all of the development of a cup and cone. On some of the transverse specimens from the forged steels, the tensile fracture showed a certain amount of lamination. This was particularly evident in the transverse specimens of the wrought irons.

The appearance of the fatigue fractures was decidedly interesting. A fatigue fracture produced upon a specimen of forged steel in which the grain runs longitudinally is usually almost perfectly flat and extremely fine in texture. It is frequently possible to detect the ripple marks which indicate the advancing steps of the fracture, but these usually run in a direction which is quite regular and undisturbed, springing from the position at which the fracture commenced. This appearance was maintained on the longitudinal specimens taken from the present materials, but the transverse specimens gave decidedly different results. Their appearances are worth separate consideration.

The material as cast showed no unusual features in the transverse fatigue specimens (FT). The fractures were quite flat, and were similar in appearance to those obtained from the specimens with the longitudinal grain. In the first forged slab (CT) the transverse fracture was very nearly but not quite flat, and across the surface ran some very faintly visible parallel cracks. In the forged slab next produced, the longitudinal fractures were

perfectly normal, but the transverse specimens (DT) showed rather obvious steps. It certainly appears as though the fatigue fracture, which in a longitudinal specimen progresses uniformly across the section of the specimen, had not done so on the transverse specimen. It appeared to have travelled for a short distance at right angles to the axis of the specimen in the usual way, then to have travelled for a short distance parallel to the axis of the specimen, then at right angles to the axis, and then parallel to the axis, and so on. The net result was that the surface appeared to be marked with a few fairly obvious cracks.

In the final forged slab the parallel rulings on the fractures of the transverse specimens (ET) were very marked. The distance between the cracks was less than in the specimens DT, and the lines were almost exactly parallel and very obvious. In samples G, which were taken from a boiler plate, the transverse specimen showed some very fine cracks rather widely spaced, the distribution being more like that on DT than on ET. The cracks were not so obvious as on ET. Specimens HT, which was the nickel chromium steel slab, showed scarcely anything worthy of comment on the part of the fracture in which failure had commenced. One part of the transverse fatigue break was very similar in appearance to a longitudinal fracture, but when the fracture had proceeded a certain distance and a fairly sudden failure had occurred over the remainder of the area of the section, the laminations or rulings were faintly visible. In the samples of wrought iron J, the parallel rulings were very obvious. They were also spaced widely and were quite coarse, and the fracture of the specimen was very markedly stepped. Some portions of the fracture were considerably higher than others, and the stepping was clean and almost rectangular on the parallel laminae. On the other hand, in the samples of Armco iron the transverse fractures (MT) were only very slightly scored. There were very faint parallel cracks on the fracture, the appearance of these specimens being somewhat like that of the nickel chromium steel.

These fractures are interesting, and it is evident that the direct path across the specimen is not the easiest one for the fracture to take. Where the material is coarsely fibrous, the path of the fatigue fracture is exceedingly ragged, as in JT. On the other hand, where the material is very finely fibred the fracture is fine

in texture, or apparently so, as in HT and MT. The appearance of the fractures in the transverse specimens, in which the fracture takes place on a plane which is parallel to the length of the fibres composing the grain of the steel, suggests that it is easier for the fracture to proceed in between the fibres than across them. The stepping which appears as parallel rulings, and the tiny cracks at right angles to the surface of the fracture, all point in this direction. The longitudinal splitting during running of the wrought iron specimens in the endurance tests points to exactly the same conclusions.

It would appear that the fatigue fracture starts across the specimen in the normal way, but that after travelling a short distance it encounters the junction of two fibres. At the junction an easy path in between the fibres presents itself and the fatigue break tends to run that way. The indubitable fact that the fibres, even in the most perfect metals, are separated slightly but definitely by a thin layer of non-metallic impurities, means that the separation of the adjacent crystals and metal already exists, and it is only necessary for the fatigue stresses to complete and widen the rupture. The applied stresses on the test-piece also, however, tend towards a transverse fracture (as opposed to the axial fracture between the fibres), and consequently the break proceeds still further across the specimen, encountering the next inter-fibre junction. The bifurcation of the crack is then repeated. The same thing happens at each junction of the fibres that is encountered. At times the separation of the fibres is so easy that the fracture of the specimen proceeds wholly in that direction for a notable distance before proceeding again across the specimen in the direction perpendicular to the axis. This is very noticeable in the wrought irons, in which the adjacent layers of material are notably bound together more loosely than in good steel.

There is some evidence that the fracture does not always proceed across the specimen in a direction parallel with the rulings or absolutely at right angles to the rulings. Sometimes it appears to have spread, or started to spread, in a direction which is inclined to the rulings at angles between 0° and 90° . Nevertheless, the result is the same in that the fibres have been parted by tiny cracks running parallel to the axis of the test specimen, and therefore running between the fibres of the steel.

Surveying as a whole the results that have been obtained, it would appear that steel or iron is not quite so strong in fatigue when stressed in specimens whose axis is at right angles to the grain of the material as when stressed in specimens in which the axis is parallel to the grain of the material. The difference in strength between the two directions is, however, not very great. The maximum difference observed in the experiments that have been carried out is 16·7 per cent. This relatively small difference is comforting to the user of materials, but requires to be accounted for. It was thought that the explanation might be found in the distribution of the non-metallic impurities, but this scarcely seems to be reasonable in view of the behaviour of the wrought iron in which a very large quantity of slag was found. There is no greater discrepancy between the longitudinal and transverse specimens of wrought iron than between those of Armco iron or high tensile nickel chromium steel.

The simplest explanation that seems to cover the observations is the following. It has been shown by one of the authors¹ that fatigue stressing is a process of cold-working, and that the governing factor in the fatigue of a metal is the extent to which it is cold-worked by the fatigue stress. The crystals on the surface of the specimens will be worked equally by the stresses, whether the specimens are longitudinal or transverse, unless there is some condition apart from the nature of the stressing to produce a difference. This cold-working is connected with the micro-crystals rather than the macro-crystals. There is no reason, therefore, to expect any difference in fatigue value in the longitudinal and transverse specimens, because the micro-crystals in the two are identical. The influence of the fibres may, however, make a difference. There can be no question that if a fine crack or inter-fibrous separation exists on the surface of the metal there will be a local increase of stress. This naturally and necessarily means that the local fatigue stress is greater than it would be in the absence of the crack. Consequently, the saturation by cold-work of the crystals in the locality will be accomplished at an apparently lower mean applied stress. Such surface cracks may or may not be present in a specimen. In the longitudinal specimens they may be accepted as comparatively absent. In the transverse

¹ Aitchison, "Cold-Work and Fatigue," *H.M. Stationery Office*, 1924.

their presence is fortuitous, and the fatigue results on the transverse specimens appear to be equally so. The behaviour of the specimens examined by the deflection method appears to support this view. The greater regularity of the endurance specimens may possibly be accounted for by the shallowness of the surface cracks. The original crack may well have the effect of cold-working the adjacent crystals, but by so doing may cause such a temporary strengthening as to redistribute the effect of the stresses almost sufficiently to cause the specimen to behave as though the crack were not present, until the whole of the highly stressed surface breaks down in consequence of saturation by cold-work.

It has also been mentioned already that even the transverse specimens have a kind of longitudinal grain, due to the flattening of the fibres. This may tend definitely to obscure the effect of the "transverse" grain of the metal, and therefore to give less difference between the specimens cut in the two directions. It seems fairly certain that such an effect has occurred. The flattening of the fibres will also have lessened the likelihood of the outcropping of inter-fibrous defects on to the surface of the test specimen in a direction that would affect the stress distribution.

SUMMARY.

The report deals with the mechanical properties, particularly the fatigue strength, of steels when tested upon specimens taken parallel to, and at right angles to, the direction of elongation during forging. It is confirmed that the direction of the grain has a marked influence upon the ductility recorded in the tensile test and upon the toughness as recorded by the impact test. The maximum stress of the material when stressed in the two directions is not appreciably different. It is found that there is not such a large difference between the fatigue strength of the steel when tested in the two directions as had been supposed. It is universally found that the fatigue strength, as shown by tests on specimens cut parallel to the direction of forging, is higher than that obtained from specimens cut at right angles to this direction, but the difference between the two is not great. The maximum difference that has been found is less than 20 per cent.

The test results have been obtained by examining, first of all,

a complete series of specimens, commencing with a large steel cast ingot and followed by specimens in different stages of forging, the final specimen representing a reduction in cross-sectional area of 96 per cent. from the original casting. Besides this basis series of specimens, tests have been made upon commercial mild steels, high quality nickel chromium steel, wrought irons from Staffordshire, and Armco iron.

Considerable variation has been observed in the mode of propagation of the fatigue crack in specimens oriented in the different ways. Some explanation is given of the cause of this variation.

The work reported upon in this paper was carried out on behalf of the Engineering Research Board of the Department of Scientific and Industrial Research, who made a grant. The authors' thanks are due and gratefully given for the assistance of the Board, and also for the permission to publish the report.

CORRESPONDENCE.

Mr. J. A. JONES (Research Department, Woolwich) wrote that in tests on material taken in the longitudinal and transverse directions from

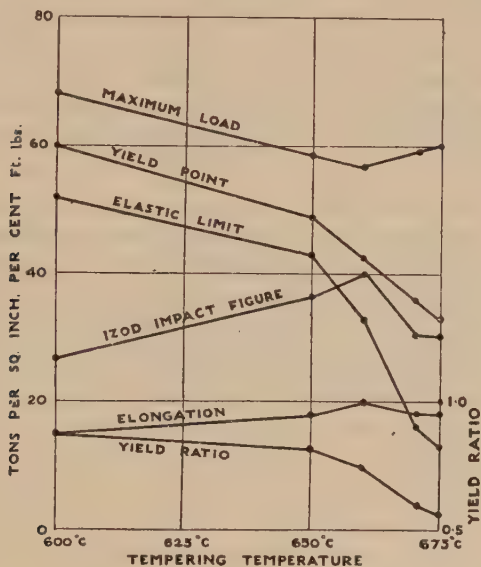


FIG. A.

forgings of carbon and alloy steels the differences found in elastic limit, yield point, and maximum load had always been exceedingly small. His results for elongation, reduction of area, and notched-bar impact figure agreed with the authors' observations. With reference to the nickel chromium steel mentioned on p. 366, he had never come across differences of that order for elastic limit and proof stress due to direction only. It would be noticed that only a single pair of results was given for that steel. He understood that the specimens were cut before heat treatment. The tempering temperature was 675° C., and he would like to point out to the authors for their consideration that at such a temperature a very slight variation would have an enormous influence on the mechanical properties. It was well known that in alloy steels tempering at temperatures considerably below the beginning of A_{c1} , as given by thermal

curves, followed by rapid cooling, might result in a considerable degree of hardening accompanied by a drop in elastic limit, yield ratio, and notched-bar impact figure. The drop was appreciable for a very small change of temperature. That was indicated in Fig. A. The steel contained 3.5 per cent. of nickel and 0.32 per cent. chromium; the beginning of Acl was 700° C., but after tempering above 650° C. the lowering of the elastic limit and yield point was pronounced. Exactly similar results had been obtained in a nickel chromium steel of the same composition as that used by the authors. Such a steel showed the beginning of Acl at 707° C., and began to show evidence of hardening on quenching from 670° C. He would therefore suggest that the difference between longitudinal and transverse tests obtained by the authors in that case was the result of a slight variation in the tempering temperature of the two test-pieces, and that generally nickel chromium steels behaved in a similar manner to other steels as regarded effect of direction on the mechanical properties.

Dr. AITCHISON and Mr. JOHNSON wrote that they thanked Mr. Jones for his remarks on the paper. They were well acquainted with the phenomena which Mr. Jones had described, and they felt that the explanation which he gave was probably quite correct. They had never attached any particular importance to the difference in elastic limit between the longitudinal and transverse samples of nickel chrome steel examined, because their general experience was that the nickel chrome steel behaved the same as the plain carbon and other alloy steels in which the elastic properties, both longitudinal and transverse, were identical.

Iron and Steel Institute.

A METHOD FOR REDUCING THE PERCENTAGE OF PHOSPHORUS IN SWEDISH IRON BY DIMINISHING THE PHOSPHORUS IN THE CHARCOAL.

By H. VON ECKERMANN, PH.D. (LJUSNE, SWEDEN).

Six years ago an unaccountable high percentage of phosphorus was suddenly found in rough bars produced from pure Dannemora ores at the Ljusne Ironworks. Analytical tests of the ores, limestone, quartz, pig iron, and charcoal entering into the production located the trouble as being due to the charcoal, although the latter was proved to be derived from only spruce and fir.

According to earlier research work by Åkerman and Särnström, in 1888, the results of which are still quoted in every text-book of to-day, the charcoals of coniferous trees are not supposed to show any great variation in their phosphorus content. These results undoubtedly being misleading, and the Ljusne Works having specialised in the manufacture of low-phosphorus melting bars for the use of the Sheffield crucible steelworks, the author suddenly found it imperative to revise the earlier investigations.

The research work embraced the determination of phosphorus in growing trees on different soils and during different seasons, the relation between the phosphorus content of the soil and the trees, and, finally, the effect, on the percentage of phosphorus, of floating the wood to its destination. As is well known, part of the Swedish charcoal is produced in "stacks" in the forests, but part is carried down by the rivers to carbonising ovens at the works.

By analysing the wood and the resulting charcoal both at the "stacks" and the ovens, it was ascertained beyond a doubt that all the phosphorus present in the wood remains in the charcoal.

PHOSPHORUS IN GROWING TREES.

Eighteen research plots 70 × 70 feet each were picked out in the forests round the Ljusne and Woxna Ironworks. The Ljusne

forests are situated on the Baltic coast, 200 miles north of Stockholm, the Woxna forest being 80 miles west of Ljusne, and 800 to 900 feet above sea-level. These areas were representative of

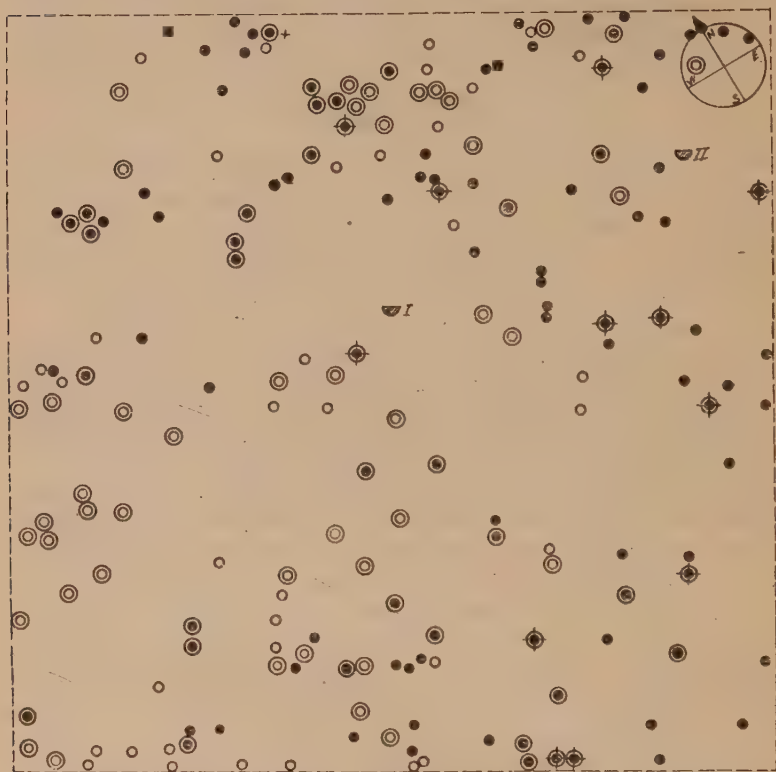


FIG. 1.—Fir, Sixty Years Old, on Wet Soil at Woxna. (Wfw-60.)

young forests (60 years old) and old forests (120 years old) growing on hard dry soil, soft wet soil, and dry sandy soil.

Every square was carefully mapped, some of the areas being shown in Figs. 1 to 4. The firs are represented by dots within circles for trees older than fifty years, and dots only in the case of trees younger than fifty years—the corresponding signs for spruces being double and single circles. The trees subject to investigation are marked with a cross through the circles; other

trees than spruce and fir are indicated by a small cross. Pits dug for sampling the soil are represented by shaded half-circles.

Within every research area two groups of six trees were chosen,

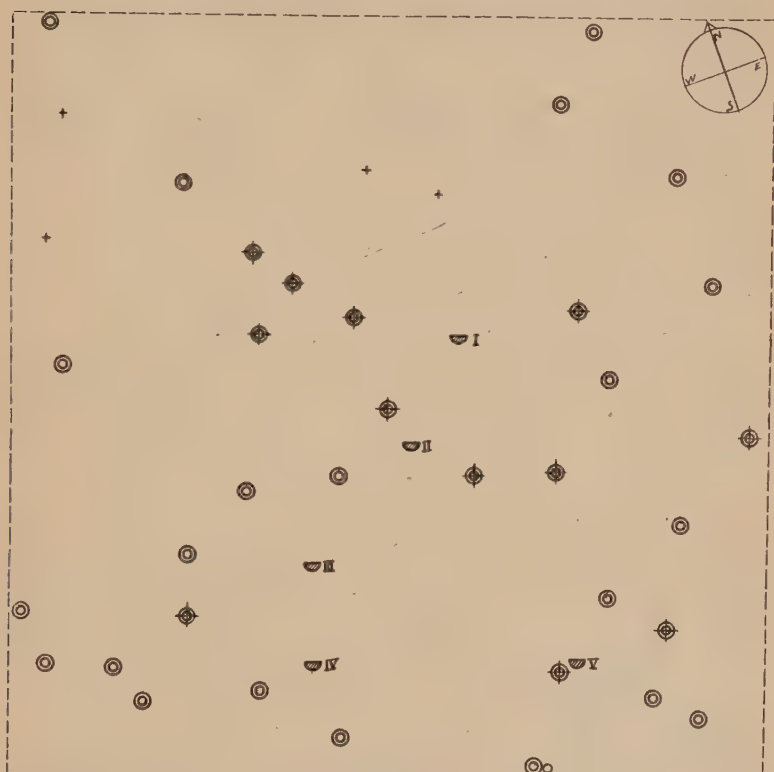


FIG. 2.—Spruce, 120 Years Old, on Dry Soil at Woxna. (Wsd-120.)

care being taken that each group represented similar trees. Drill-core samples were taken from the trees right through the centre every second month, starting on January 15, 1920, and finishing on January 15, 1921. The samples relate to bark, surface wood, living wood, centre wood, and dead wood. At the same periods the smaller branches were sampled and analysed with the bark on, and also the needles. The analytical work aggregated 5052 analyses, of which by far the bulk was carried out at the author's private research institute.

The analyses are given in full in the *Journal of the Society of Swedish Ironmasters (Jernkontorets Annaler, 1924)*, but in order to afford a more comprehensive view of the results, the averages of each research area are shown in diagrams (Figs. 5 to 10). The

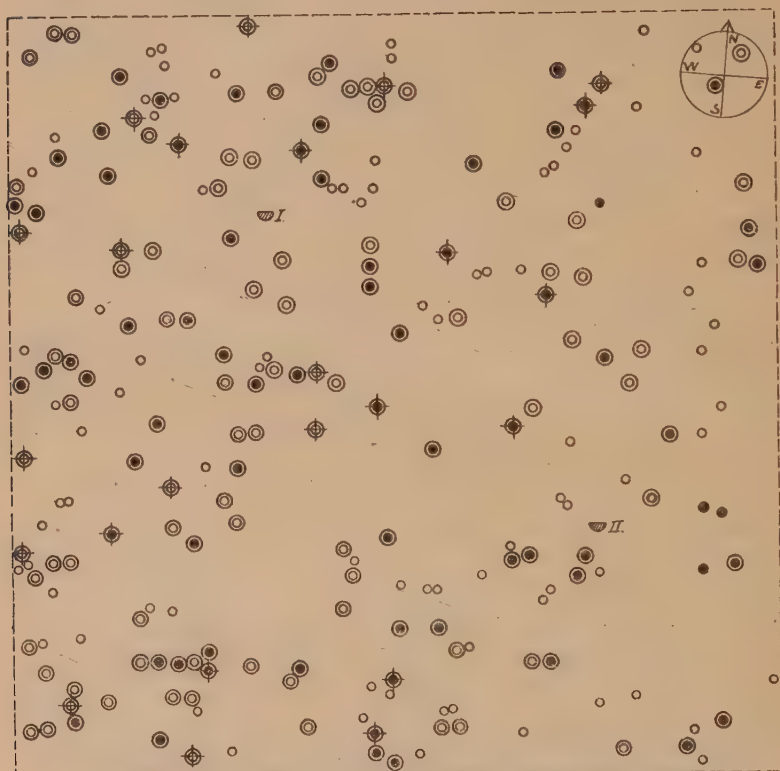


FIG. 3.—Fir, Sixty Years Old, on Wet Soil at Ljusne. (Lfw-60.)

different curves are indicated by initials—L meaning Ljusne ; W, Woxna ; f, fir ; s, spruce ; d, dry soil ; w, wet soil ; s, sandy soil. Lfw-120 thus reads Ljusne fir, wet soil, 120 years old ; Wfs-60, Woxna fir, sandy soil, 60 years old, &c.

The author's observations confirmed the already known fact that the centre wood contains less phosphorus than the surface wood, and the branches and bark reveal percentages which amount to ten to fifteen times those of the wood. The phosphorus in the

centre wood runs on an average to about 0·0025 per cent. and varies within small limits, 0·0005, up and down—all the variation being really confined to the surface wood, in which the phosphorus has been found to vary from 0·0231 per cent. down to 0·0030 per

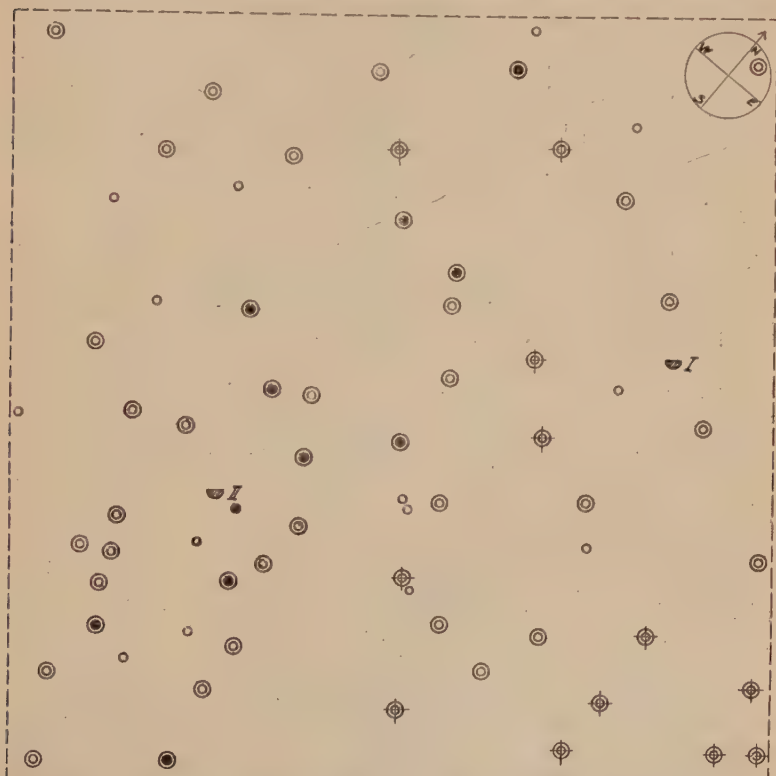


FIG. 4.—Spruce, 120 Years Old, on Dry Soil at Ljusne. (Lsd-120.)

cent., the average variation being greater at higher levels above the sea than at lower.

Because of the nearly constant percentage of phosphorus in the centre wood, the diagrams in Figs. 5 to 10, representing the average contents of phosphorus in the wood, actually denote the variations in the surface wood.

As a successive variation of the amount of phosphorus is proved to exist between the minimum value of the lower part

of the trunk, where the centre wood predominates, and the maximum value of the branches, the charcoal produced in "stacks"

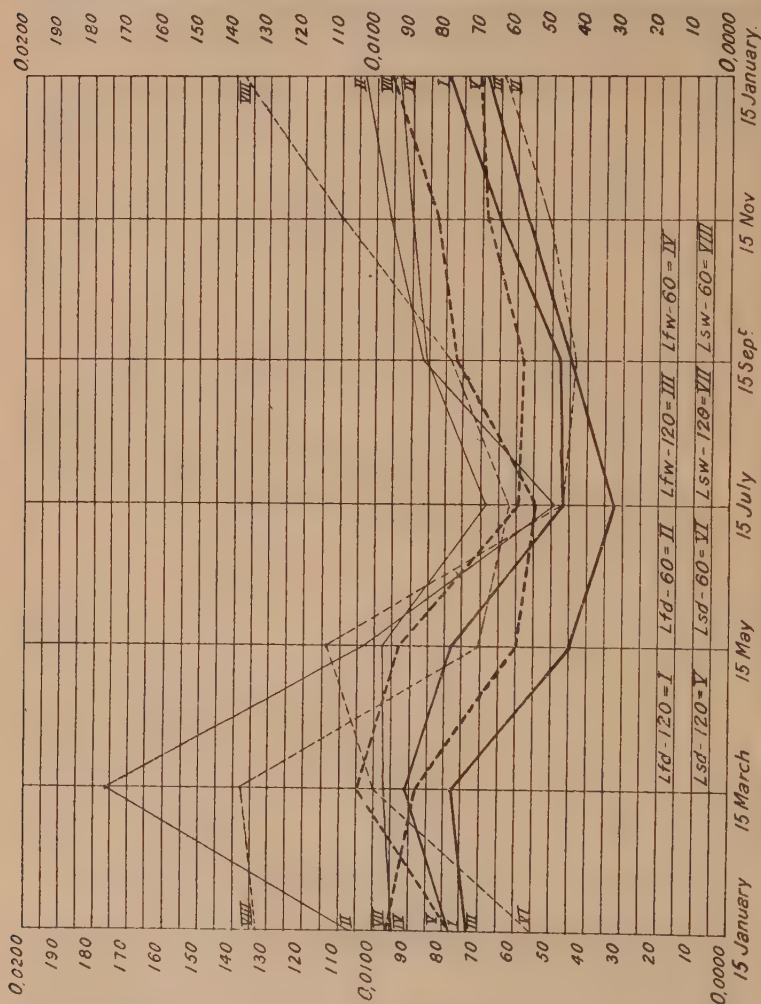


Fig. 5.—Variations of Phosphorus in Charcoal derived from Wood at Ljusne.

in the forests gets richer in phosphorus the more branches are put into the stacks.

Richest of all in phosphorus are the needles. As an average they have been found to contain 0.1 per cent. phosphorus, which amounts to more than 100 times that of the centre wood, and 25

to 50 times that of the trunk average. The old practice of the Swedish ironworks of covering their stacks in the forests with green

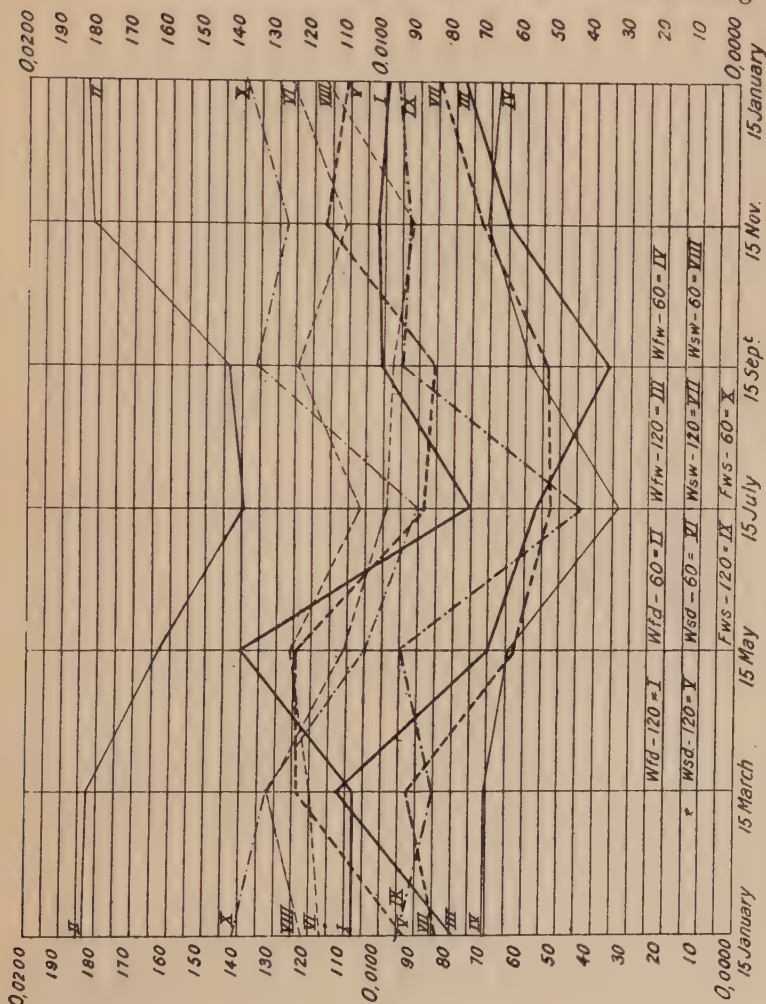


Fig. 6.—Variations of Phosphorus in Charcoal derived from Wood at Woxna.

branches of spruce therefore introduces into the charcoal a large quantity of high phosphorus charcoal dust from the needles, which to a certain extent could be avoided.

The older the forest, the larger will be the percentage of centre wood in the trees, and consequently the lower the average amount

of phosphorus in the charcoal. A special series of observations was made on trees of different ages close to research squares Nos. 5

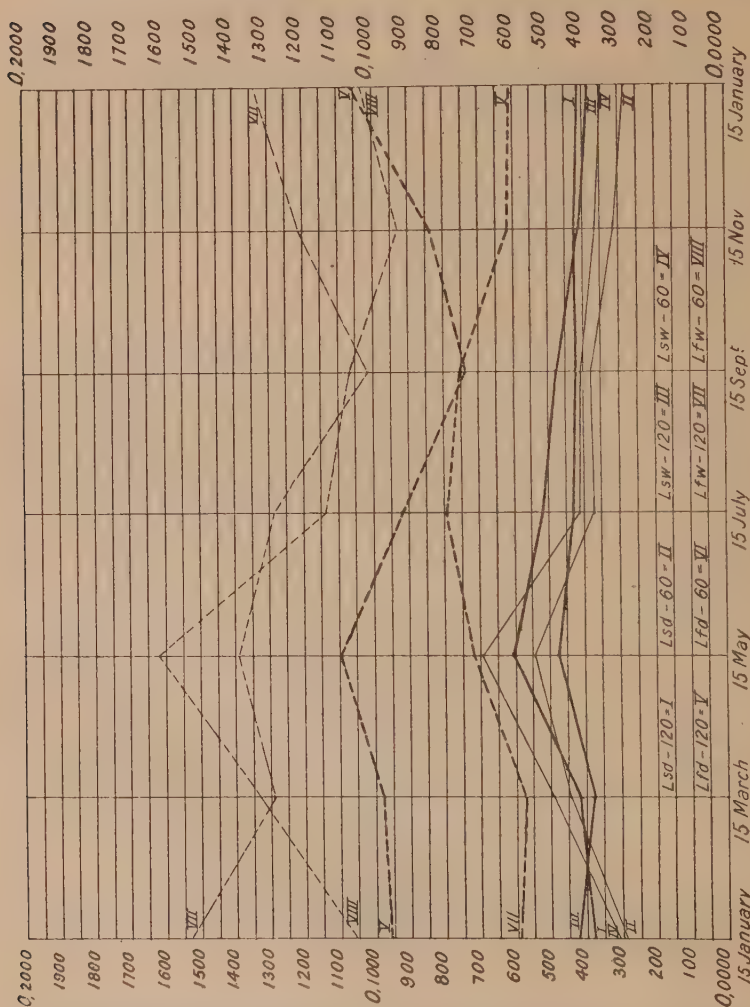


Fig. 7.—Variations of Phosphorus in Charcoal derived from Bark at Ljusne.

and 8, and the results are found plotted in the diagram (Fig. 11), where the remarkable conformity of the centre-wood curve and the phosphorus curve will be noted.

The old trees as well as the young show a very pronounced variation of phosphorus content with the varying seasons of the

year. Studying the curves Figs. 5 to 10, it will be found that the phosphorus in the wood and bark decreases from a maximum value

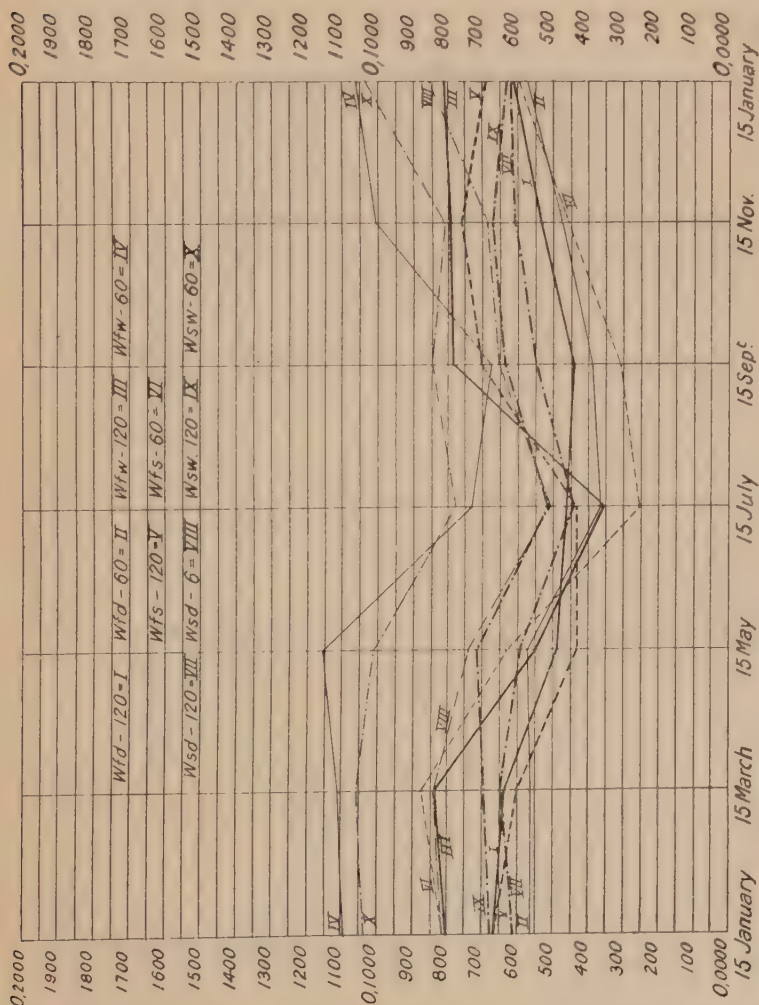


Fig. 8.—Variations of Phosphorus in Charcoal derived from Bark at Woxna.

in early spring towards a minimum in July to September, and thereafter increases again, to remain about constant during the winter. The mounting of the sap in the spring often indicates the very maximum, especially in the case of the bark.

The branches, on the other hand, have their phosphorus

maxima in summer, with a local secondary minimum occasionally about July 1. Schematically, the varying of the phosphorus with

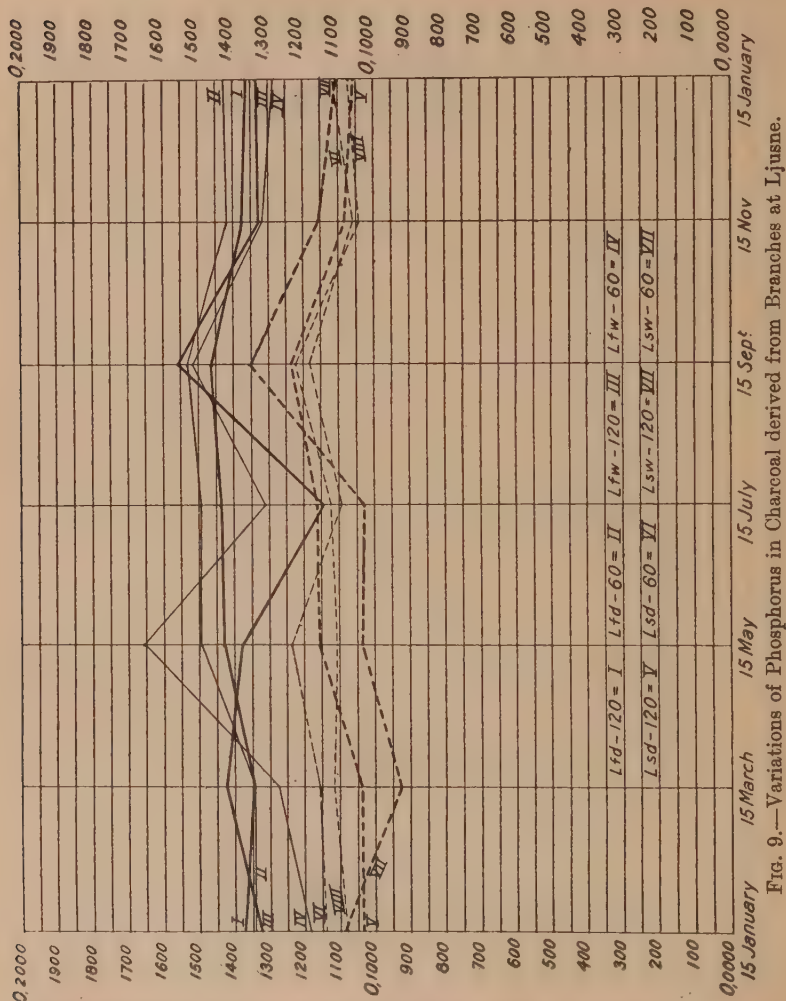


Fig. 9.—Variations of Phosphorus in Charcoal derived from Branches at Ljusne.

the seasons is shown in the diagram (Fig. 12), which may be explained by assuming a transference with the mounting sap of soluble phosphoric nutrition salts which move from the trunk out into the branches, to be consumed there in the sprouting of the needles. Thereafter a gradual accumulation of new phos-

phorus takes place in the surface wood as long as the autumn lasts, to be kept in store during winter to meet that urgent demand

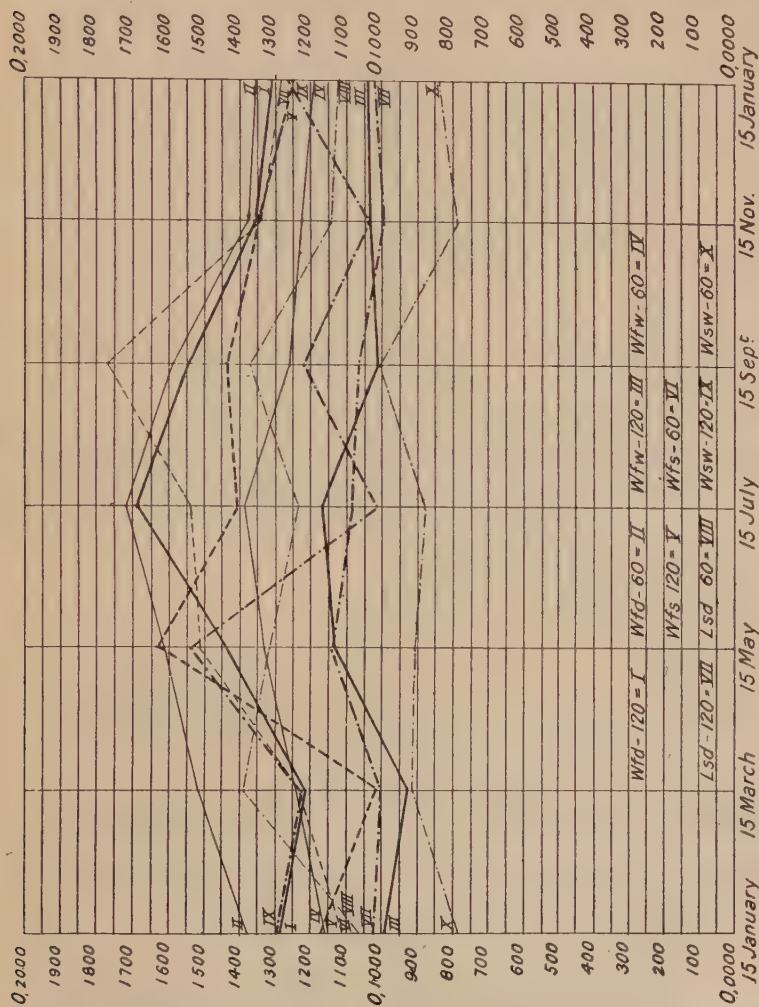


Fig. 10.—Variations of Phosphorus in Charcoal derived from Branches at Woxna.

in the spring which the roots alone cannot supply out of the soil.

The local branch minima may be explained by the large phosphorus consumption during the fruit setting, when the nutrition feeders are temporarily drained, to be refilled later.

In order to reduce the percentage of phosphorus in their fuel

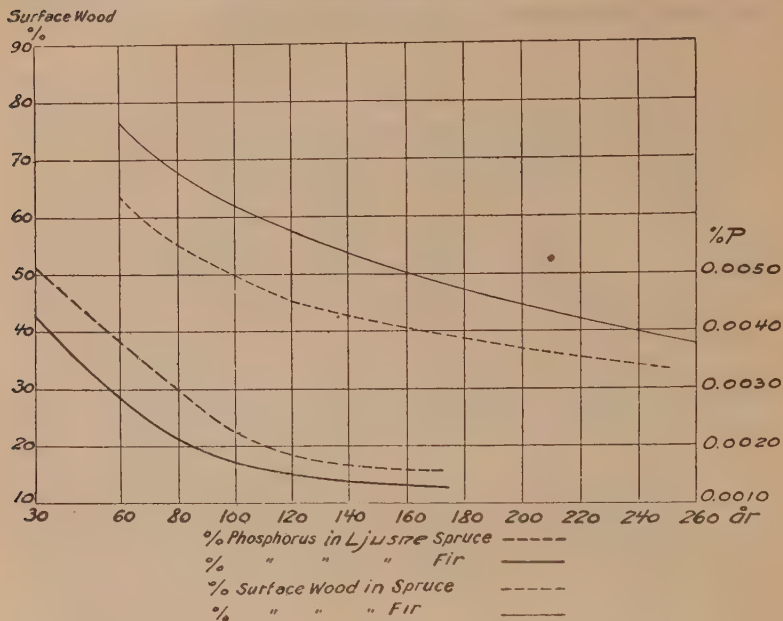


FIG. 11.

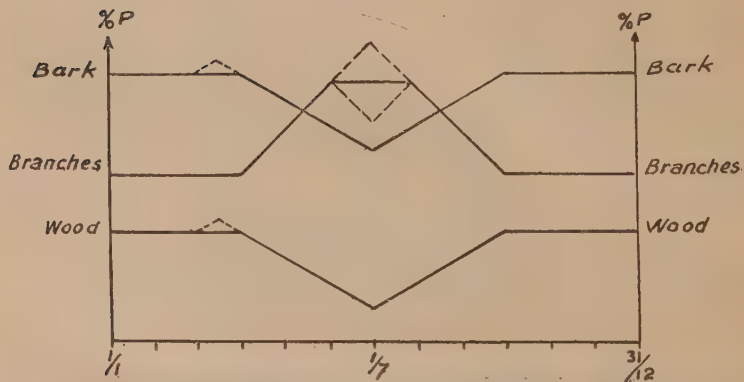


FIG. 12.—Variation of Phosphorus in Charcoal derived from Wood cut at Different Seasons of the Year.

the Swedish ironworks should therefore not cut their charcoal wood in the late autumn, early winter, or spring, which in many

places has hitherto been the normal practice, but in the middle of the summer.

The modern management of the forests with frequent thinning-out to let the sunshine and the air into them certainly leads to a quicker growth and larger crowns. But larger crowns require larger quantities of phosphorus to be stored in the trunk and moved in spring through the branches. The increasing danger of getting high phosphorus charcoal, when cutting the wood at the wrong season, is therefore happily counteracted by the increased knowledge of the phosphorus circulation of the trees, gained through the present investigation.

RELATION BETWEEN THE PHOSPHORUS CONTENT OF THE SOIL AND THE TREES.

Several pits were dug on each research area, the depth of the weathering and the underlying oxidation zone measured, and the amount of phosphorus analysed. Forty-six analyses were made, of which the following two examples may be given :

	Weathered Soil. Phosphorus per Cent.	Oxidation Zone. Phosphorus per Cent.	Unaltered Soil. Phosphorus per Cent.
Ljusne forest slightly weathered. Lsd-60, plot No. 11	0.021	0.031	0.026
Woxna forest, strongly weathered. Wfw-120, plot No. 4	0.007	0.062	0.026

The surface water dissolves the phosphorus, which is carried down and precipitated with iron oxide in the rusty oxidation zone. This alteration of the homogeneity of the soil certainly has some influence on the life of the trees, and one would expect that a very much-weathered soil, where the phosphorus has been soaked out, would, as long as the roots do not penetrate to the oxidation zone, give rise to a growth low in phosphorus.

On the contrary, even if the analyses be too few to be conclusive, everything points to an increase of phosphorus in the trunks when the phosphorus of the soil decreases. A reasonable explanation may be the greater need of storing a larger amount of phosphorus in the wood when the roots cannot quickly extract

it from the soil in springtime, which especially applies to higher altitudes, where the period of vegetation is a shorter one. Another indication of the same nature is the more extensive storing of phosphorus in trees growing on moist soil than in those growing on dry soil.

Forests growing in lava and greenstone districts may therefore, generally speaking, be expected to yield charcoal of a better quality than those which grow on a quartzitic rock ground.

THE SOAKING OUT OF THE PHOSPHORUS THROUGH FLOATING THE WOOD.

Forty logs of spruce and fir were specially marked in January 1920, put on the frozen river, and analysed for phosphorus. They arrived at Ljusne about the end of October and were sampled again. Leaving them in the water, new determinations of the phosphorus took place at the end of the years 1921 and 1923.

The average percentages of phosphorus in the charcoal are given in the following table :

	Prior to Floating, 1920.	Floated, 1920.	Floated, 1921.	Floated, 1923.
Fir :	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Centre wood . .	0·0029	0·0020	0·0016	0·0010
Surface wood . .	0·0184	0·0089	0·0067	0·0058
Spruce :				
Centre wood . .	0·0019	0·0017	0·0014	0·0012
Surface wood . .	0·0166	0·0081	0·0066	0·0054

A corresponding investigation of phosphorus in charcoal from wood, towed in the salt water along the Baltic coast, also showed a decrease in the amount of phosphorus, but decidedly less, and varying with the percentage of salts in the water.

The analyses show beyond doubt that a remarkable soaking out of the phosphorus takes place during floating, the fir falling to minimum values quicker than the spruce. It has also been found that the warmer the water the quicker the removal of phosphorus, hence a warm summer should give better charcoal from floated logs than a cold one.

By floating the charcoal wood from the forests down the rivers to the works or to permanent carbonising plants, the Swedish ironworks will be able considerably to improve their charcoals, and thereby also their iron and steel. Through experiments at the Ljusne Works it has recently been ascertained that even very small sizes of wood can be floated by bundling them together with iron wire, $\frac{1}{8}$ inch thick. The bundles are put into the carbonising furnaces as they arrive, and the wire accompanies the charcoal and is remelted in the blast-furnace.

THE IMPORTANCE OF LOW PHOSPHORUS CHARCOAL FOR THE SWEDISH IRON TRADE.

The Swedish iron industry is mainly based on the production of very high qualities of iron and steel, low in sulphur and phosphorus. The low phosphorus ores of the country and the charcoals derived from the extensive forests supply the necessary natural resources.

As all the phosphorus introduced into the blast-furnace through the ores and the charcoal will practically be found in the resulting pig iron, every improvement in the purity of the fuel means either the possibility of using lower grade ores or of cutting down the percentage of phosphorus in the pig iron, giving either a cheaper product or a higher quality.

The use of low phosphorus charcoal is of special importance in the production of so-called "Lancashire rough bars," which bars, on account of their purity, are used for the production of blister steel, and as charges for electric furnace and crucible steel melting.

Lancashire iron derives its name from Lancashire in England, where the method arose and was, later, transferred to Sweden (about 1830). When melting the pig iron on small hearths with charcoal in a hot-blast some of the phosphorus of the pig is oxidised and carried into the slag, but some phosphorus is also added by the charcoal ashes. As the Lancashire iron is built up of grains of practically pure ferrite mixed with small inclusions of slag, which are more numerous in the rough bars than they are, later, in a welded iron, the percentage of phosphorus in the slag has a decisive influence on the phosphorus content of the iron.

The lower the amount of phosphorus in the charcoal ashes, the less there will be in the melting bars.

In the old days, the Sheffield crucible works hardly ever asked for analyses of a Swedish rough bar. They kept to certain brands manufactured from certain ores, and were satisfied if the resulting steel showed the high quality required. To-day chemists are evaluating the quality of an iron by computing the analysed quantities of sulphur, phosphorus, oxygen, nitrogen, hydrogen, &c., present, and even if one does not always agree with their standards of value, the Swedish ironworks have certainly tried to meet their demands. It is not for the author to say whether the reduction of the percentage of phosphorus in the melting bars another four or five points below the normal quantity of 0.020 per cent. improves the quality of the steel, but if such be the case, his research work on the phosphorus of the Swedish charcoals has certainly shown a method of achieving this.

SUMMARY.

Research work has been conducted on so large a scale that occasional differences can be considered as eliminated, and the amount of phosphorus in charcoal derived from the Swedish fir and spruce forests has been determined.

A considerable reduction of the phosphorus content of the charcoal has been shown to be obtainable by cutting the right parts of the trees at the right season and floating the logs down the rivers to the carbonising plants.

Further, it has been pointed out how by lowering the amount of phosphorus in the charcoal the range of Swedish ores available for the production of high-grade pig iron may be extended as well as the quality raised. The manufacture of melting bars for the Sheffield trade, so far as quality depends on a low percentage of phosphorus, may, by such means, be very much improved.

Iron and Steel Institute.

THE ESTIMATION OF PHOSPHORUS IN THE PRESENCE OF VANADIUM.

By G. WATSON GRAY, F.C.S., F.I.C. (LIVERPOOL),

AND

C. DURHAM GARBUTT, F.C.S., M.INST.MET.

MANY methods have been published describing the estimation of phosphorus in the presence of vanadium, but in the hands of the present authors none have proved satisfactory. Some have been unreliable, while others have proved too long and tedious. After many experiments a method has been devised which has been found reliable and at the same time reasonably quick. It consists of getting the material into solution, removing the silica, separating the iron with ether, precipitating the phosphorus with magnesia mixture in the presence of citric acid, dissolving the ammonium magnesium phosphate in nitric acid, and then estimating the phosphorus as molybdate.

A detailed description of the method is as follows :

Two grammes of the finely powdered alloy or other material to be tested are dissolved in 50 cubic centimetres nitric acid of 1.2 specific gravity in a 600 cubic centimetre squat beaker, and after the action has ceased 5 cubic centimetres of hydrochloric acid are added and the solution digested for ten minutes. It is then evaporated to dryness to render any silica insoluble and taken up with 25 cubic centimetres of hydrochloric acid. The solution is diluted, filtered, and the paper washed free from vanadium and iron by means of water containing 100 cubic centimetres of hydrochloric acid per litre. The insoluble matter is burnt off and treated with hydrofluoric acid and the residue fused with nitre mixture, the melt dissolved in water, the crucible cleaned with hydrochloric acid, and the solution obtained added to the original solution and evaporated to dryness.

Forty cubic centimetres of hydrochloric acid are now added, the beaker covered and the solution allowed to simmer for ten to fifteen

minutes, or until no more chlorine is evolved. At this stage all the vanadic acid will be reduced. This is necessary and important, as if any vanadic acid remains unreduced all the phosphorus will not be obtained by the subsequent ether separation. The solution is now cooled and transferred to a separator with hydrochloric acid of 1.105 specific gravity. An equal volume of ether is now added, and the whole shaken vigorously for two minutes and allowed to separate. The acid solution containing the vanadium together with the whole of the phosphorus and arsenic is then tapped off into the original beaker. The ether solution is given a wash with 5 cubic centimetres of hydrochloric acid of 1.105 specific gravity, and this is added to the larger portion. The acid solution is re-treated with ether to remove any traces of iron still remaining, and then warmed gently until the dissolved ether is expelled, and the acid solution is again evaporated down until it is pasty. The sides of the beaker are washed down with hot water and 6 grammes of citric acid added. At this stage the solution should be perfectly clear. It is transferred to a 300 cubic centimetre tall form beaker, washed in and cooled. The bulk of the solution should now be about 120 cubic centimetres. Excess of ammonia and further ammonia equal to 25 per cent. of the bulk of the liquid is added. This will make the volume of the solution about 160 cubic centimetres; 10 cubic centimetres of magnesia mixture are now added drop by drop, stirring vigorously, and the stirring continued for ten to fifteen minutes, the solution being left to stand overnight. The precipitate is filtered off on a suitable paper, the beaker washed on with water containing 10 per cent. ammonia and 2 per cent. ammonium nitrate and the paper washed free from vanadium. If arsenic be present in the sample, the whole of it will be in this precipitate. The precipitate is dissolved in hydrochloric acid, and the arsenic removed as sulphide by hydrogen sulphide. The filtrate from the arsenic precipitate is boiled to expel H_2S , oxidised with nitric acid, a little ferric chloride added, and the iron and phosphorus precipitated with ammonia, filtered and dissolved into a 200 cubic centimetre flask with nitric acid, and precipitated with molybdate as usual.

Everyone must recognise the need for an accurate method for the estimation of phosphorus in ferro-vanadium. We have

examined samples in which the phosphorus varied from 0·02 per cent. to as much as 1·60 per cent. If high phosphorus material be supplied to steel-makers who do not work under strict analytical control, but take the suppliers' word that the alloy supplied is of good quality, it is not surprising that some bad alloy steel is made.

CORRESPONDENCE.

Mr. T. E. ROONEY (Teddington) wrote that the most satisfactory method he had used for the estimation of phosphorus in presence of vanadium was that described by Cain in Technical Paper No. 24, Bureau of Standards.

The method proposed by the authors appeared to him to be rather long and complicated for ordinary use. In the presence of tungsten the method would be unreliable, as phospho-tungstic acid was soluble in ether.

In his (Mr. Rooney's) opinion, the precipitation of ammonium-magnesium phosphate in presence of citric acid was apt to be uncertain. Also, as the authors had proposed dissolving the ammonium-magnesium phosphate in nitric acid and estimating the phosphorus as molybdate, it would appear to be unnecessary to remove any arsenic that might remain by precipitating as sulphide. He would prefer to precipitate the phosphorus as phospho-molybdate at a temperature not exceeding 40° C.

In the paper there was no indication that the method proposed had been tested out by estimating known amounts of phosphorus in presence of varying amounts of vanadium.

Mr. WATSON GRAY wrote, in reply to Mr. Rooney's remarks, that the method proposed was not meant for a rapid works method, but rather aimed at accuracy combined with reasonable speed. If carried out as directed all the phosphorus would be obtained in the presence of the amounts of tungsten sometimes present in ferro-vanadium.

The precipitation of ammonium magnesium phosphate was complete in the presence of the amount of citric acid recommended to be used, and indeed in the presence of much larger quantities. With regard to the separation of arsenic before precipitating the phosphorus by ammonium molybdate, as some ferro-vanadiums contained arsenic 10 or 20 times greater than the amount of phosphorus present, the little extra time occupied in removing the arsenic was well spent.

Although details of the trying out of the method were not given, numerous series of experiments were made with varying proportions of vanadium and phosphorus as well as with the other usual constituents of ferro-vanadium, and with varying amounts of the reagents employed.

ANNUAL DINNER.

THE Annual Dinner of the Iron and Steel Institute was held at the Grand Hall of the Hotel Cecil on Thursday, May 7, 1925, under the Presidency of Sir Frederick Mills, Bt., D.L. Amongst the other distinguished guests present on this occasion were the Rt. Hon. Sir P. Cunliffe-Lister, K.B.E., President of the Board of Trade ; the Rt. Hon. Lord Gainford ; the Rt. Hon. John Hodge ; Mr. Evan Williams ; Sir Herbert Walker, K.C.B. ; Mr. P. W. L. Ashley, C.B. ; Sir Henry Livesey, G.B.E. ; Sir William Peat, C.V.O. ; Sir Harry Peat, K.B.E. ; Sir Ernest Hatch, Bt., K.B.E. ; Sir Joseph Petavel, K.B.E., F.R.S. (Director, National Physical Laboratory) ; and the Presidents of a number of kindred Institutes. Sir Frederick Mills, Bt., was supported in the Chair by Sir William Ellis, G.B.E., D.Eng., and Mr. Francis Samuelson, Past-Presidents of the Institute ; Mr. Iltyd Williams, Hon. Treasurer ; Sir W. Charles Wright, K.B.E., C.B. ; Sir W. Peter Rylands ; Mr. F. W. Harbord ; and Mr. M. Mannaberg, Vice-Presidents of the Institute ; and by a number of Members of Council.

Sir WILLIAM ELLIS, G.B.E., D.Eng. (Past-President), in proposing the toast of "His Majesty's Ministers," said that while the Institute would have been very happy to have welcomed any member of the Government to their gathering that night, there was a special reason why it was both apt and fortunate that Sir Philip Cunliffe-Lister was present as a guest. Presiding as he did over the Board of Trade, he was conversant with the great difficulties under which the industry was suffering. It was difficult indeed to admit that at present any light could be seen coming through the encircling gloom. When he (Sir William) had had the honour of presiding at that gathering in the previous year he had welcomed amongst them several members of the then Government. Whether the Institute as a whole agreed in politics with the Government which was in power or not, it was always glad that its Ministers should visit them, and take a part in considering the difficult

problems which confronted it. Sir Philip Cunliffe-Lister was present under very different circumstances; he represented a Government strongly supported by the constituencies, and every one would hope that that strength would be used to good effect.

When the Government came into power last November, there went through the country a strong wave of optimism that now that a strong Government was in power, industry was going to improve. He (Sir William) had not been one who had shared in that optimism; he had realised that a strong Government coming into power would inevitably do something in the way of inspiring confidence, but it could not remove the very serious difficulties which were preventing the développement of industry in the country. The causes of the present depression were very well known, and the extent of unemployment was perfectly well understood and simple to define.

After the war all nations were stricken by its financial effects, and although their needs for reparations and for carrying out extensions and developments, naturally deferred owing to the war, were very great, financial difficulties prevented them ordering the commodities they so much required.

Had that state of things passed away, and were the various nations in a position now to order what they required? Was their finance in such a position as to enable them to do so? He thought the answer to that was that to a great extent they were able owing to the many financial arrangements and facilities which had come into existence. But when he came to the second point, he found it very much more difficult to deal with. Assuming for the moment that he had answered the first point correctly, from whom were those various nations going to order what they required? The answer to that question was quite simple: they were going to order what they required from those nations that could give them what they wanted in the way of quality—high quality—at an economical price. That led immediately to the further question: Were we the nation which could comply with those two requirements? Great Britain could comply with the first point, as regards quality, but the answer to the second point was in the negative: it was impossible at present to supply other nations at as economical prices as they required. The circumstances were perfectly well known to the Government and to all: higher

wages in Great Britain, shorter hours relatively to other countries, and greater taxation. Those conditions inevitably resulted in a higher cost of production. That was the simple answer to the question why there was unemployment at home, and why Great Britain was not able to compete with other nations.

How were those disastrous circumstances to be combated? There were those who favoured the various unions in Great Britain approaching their colleagues in other countries and saying to them: We are not able to obtain employment in England because your wages are lower and your hours are longer; will you remedy that so as to enable us to have more employment in our own country? Not only did he (Sir William) feel that that would be a very unfriendly act of the workmen of any one country towards those of another, but it would be futile. What was the good of going to men in another country and saying to them: We are not getting the work we want; we want you to press for higher wages and shorter hours so that you shall get less work and we shall get more. It would not have the least effect, and it would be utterly wrong in principle. Foreign labour was reasonably satisfied with its conditions, and would not listen to any such argument. There were, on the other hand, substantial reasons why wages in many industries at home could not be lowered. No one wanted them lowered if it were possible to avoid it. The cost of living was high, and although there were certain anomalies which he would not allude to in detail—the sheltered trades—where wages were relatively high, there were other skilled trades—engineering and other industries—in which wages were not inordinately high, and with which he and many of his audience would sympathise deeply, in that because they were on a competitive basis they had to accept lower wages for higher skill than was paid in many other directions. It was an anomaly which was greatly to be regretted. If the attempt were made to deal with that problem by raising those wages, it would recoil to the disadvantage of those classes of men, because it would make foreign competition more serious than it was at present; no good could possibly come of taking that line.

The Government of the country was, it might be believed, fully alive to those serious facts. He would say as little as possible, and leave to Sir Philip as much time as possible, and for that reason he

would not touch on the many suggestions which were being put before the members of the Government. Some called them remedies: he (Sir William) called them palliatives. Most of them avoided facing, in a manly way, the real issues that were causing the trouble. The Minister was a member of a strong Government. That strong Government should have the courage to put before employers and workmen alike what, in their discretion and after fully weighing the various propositions put before them, they believed would lead to better times—and to impose such changes and modifications as they might think necessary.

Those present were well aware of the dislike that was felt on the part of workmen and employers alike to the dole system. There were great abuses of the dole system, and they would ask the Government to look carefully into those well-known abuses. It should be made more difficult for a man not to have to work; the difficulties of the dole should be such that, if work were available, a man should make every effort to take that work, instead of nursing himself, as was being done in some instances, behind the dole. Local taxation in all industrial centres had been enormously increased, owing to the too lax methods in dealing with those various forms of relief, and had resulted in raising the cost of production in all directions. Thousands of houses were, for example, wanted in the country. There were thousands of men able and willing to work at building houses. Such men should have freedom to work at the standard rates of wages for such classes of workmen. The Government should say plainly and with courage: If you want to work at that industry we will see that you are not knocked about; that you shall have reasonable protection. In two years' time, if that were done, there would be no house problem at home at all; all the discomfort that the various classes of workmen were suffering from at the present moment would have disappeared, and there would be plenty of houses. The present system was, he had little hesitation in saying, tyrannical!

He would assure Sir Philip, in conclusion, that all present realised what his difficulties and those of his colleagues were. They wanted to help them in every possible way. Any particulars, any details of industry, or anything that would enable the Government to frame a policy would be freely at their disposal; a fair

and reasonable trial would be given to any fair and reasonable plan. Sir Philip was an old colleague of his (Sir William) on one or two Government Committees ; it was a great pleasure to meet him again that night in his responsible position. He wished him all good wishes, and hoped he might have success in dealing with those many and serious problems.

Sir PHILIP CUNLIFFE-LISTER, K.B.E., President, Board of Trade, in reply, said he was grateful to the Institute for its hospitality, and to his old friend and colleague, Sir William Ellis, for the wise and generous way in which he had proposed the toast. They had worked together not infrequently in the past, and he (Sir Philip) could assure him that, like *Oliver Twist*, when he found something good he always asked for more, and would not hesitate to ask him and others to give him that help again which he knew would not be withheld. That was the kind of co-operation which it was the duty of a Government to seek. The iron and steel industry had behind it a long history of scientific study, which there was some little tendency to underrate. In many cases what was placed to the credit of a foreign country had had its origin in British brains and British discovery. The relations between science and industry were not always as close as they ought to be, and it was necessary to strengthen them as much as possible. British quality, British craftsmanship, and British credit were three great and lasting assets, and they should be afforded every chance to hold their own and to better their position in the markets of the world. For that purpose it was essential that in all great industries scientific research should have the fullest and the most constant opportunity. Throughout the land new universities had grown up under the shadow of the great industrial centres, owing their existence and their development in no small measure to the munificence of British industry and British commerce. That should become a real paying investment in every trade and every industry in the country, and the men who were being trained should be given the earliest opportunities of applying their scientific knowledge, not merely in the seclusion of a university laboratory, but in the more practical tests of the commercial laboratories and workshops of industry. The Government were only too anxious to assist

industry, in research, wherever it could usefully do so ; and no better earnest of that intention could have been afforded than the return to Government of Lord Balfour, who was charged in a particular degree with the care and fostering of the Department of Scientific and Industrial Research.

If it were the duty of the Government to co-operate with industries in helping research, it was also the duty of each industry to co-operate within its own borders for that purpose. In many cases the costs were too great for a single firm to undertake effectively, yet the results of applied science were of equal value and of common interest probably to every single firm within a given industry. That was, he thought, realised to a great degree on the scientific side, and he wished that spirit of co-operation in scientific research more power. Those lessons could, moreover, be applied outside the scientific sphere and rather more in the sphere of commerce. There could be the keenest competition within an industry while the industry as a whole was playing as a side against the world competition it had to face, and the more co-operation of that kind there could be the better. Sir William Ellis in his speech had spoken of the need for a national outlook. That was one aspect of it : willingness to co-operate within an industry to face common difficulties and common competition that came from outside. That common spirit and common endeavour were surely the purpose which was behind the country in its search, not for a party Government, but for a Government that would carry out a national policy. He agreed absolutely with what Sir William had said as to the vital importance of a Government having the courage to speak the truth, to face facts, and to act. That spirit should, however, permeate all alike. The members of the Institute would realise that no Government could do that which industry had got to do for itself ; it could help and it ought to help wherever it could, it could refrain from doing things which were mischievous ; but when it had done the one thing and left undone the other, it was industry itself which had to work out its own salvation. Government policy should be designed to subserve what must be the greatest national interest, the interest of trade and industry. Economy was absolutely vital. Working for settlement in foreign policy was enormously important too. It was impossible to ignore the conditions of any

part of the world, unless people were prepared to ignore its trade, and not only its direct trade but the trade which came at the second and at the third remove. While that was true it would be very foolish in difficult, abnormal, and transitional times, to allow academic prejudices to prevent whatever was necessary being done to safeguard an individual industry at home where it proved the need of such help. Action of that kind was never likely to be misinterpreted in a foreign country. Imitation even on a very limited scale was a sincere form of flattery ; and having himself had something to do with the making of treaties he could say advisedly that he had never found any difficulty in making a treaty when it was made clear that full rights to safeguard the interests of the industries of the home country were reserved. He had found that, in practice, more than once. Even a bigger share in old markets was not enough. The development of new markets was necessary, and nowhere could such a development, ready to hand under such favourable opportunities and with such willingness on both sides and such reciprocal advantages, be found as within the confines of the British Empire itself. To that policy the Government was committed, that policy it was pursuing, and that policy would be pursued unswervingly. Such a policy had, however, to be mutual. It had to be mutual in sentiment, and mutual also in ordinary commercial practice, because the great Dominions could not take a new population or produce on a large scale, unless they could find for that population and for that production a mutual and a reciprocal market at home which would take that produce in return for its goods.

There was one essential without which no policy could avail, and that was the need, the vital need, of goodwill and confidence in industry. If a Government were to have the courage to speak the truth and to act, it was no less important—it was perhaps more important—that the partners in industry should have the courage and the goodwill to face facts together, and to speak the truth to each other openly, frankly, and with confidence. They had common problems—problems which, faced in that spirit, presented an extraordinary parallelism. A union might have developed restrictions designed with the object—a perfectly reasonable object—of trying to get as much work as possible for as many workmen. Such an object might be perfectly

genuine in its intention, yet absolutely fatal in its result if the result were that the contracts did not come. That had to be faced frankly. But that had a parallelism on the other side in the importance of industries working for a small profit on a big turnover rather than for a big profit on a small turnover. There was need to be equally frank about that. There was need of confidence on the workmen's side that where a bargain was made, and a rate fixed, there would be a square deal and that the agreement would be kept; that was absolutely right and absolutely reasonable. They would have, however, to realise on their part that the counterpart was no less important: that the employer had equally to rely on a bargain being kept and on a certain output being available; because if he had not got that certainty he could not quote firm and he could not quote fine. It was those two things which were vital if contracts in a competitive world were to be obtained. If that confidence were not forthcoming, it could not be expected that money would be invested, sunk in science and in new development, where it might not see its return for many years. Goodwill and mutual confidence—the facing together of common problems—was the most important thing of all. It had been said that the British were a nation of shopkeepers. It had been said, with equal truth, that it was a nation of sportsmen. Both statements were true. They should strive to strengthen the resolution to play the game as a united side and for the side, and if that were done, nothing could withstand that combination.

THE IRON AND STEEL INSTITUTE.

The Right Hon. JOHN HODGE, in proposing the toast “The Iron and Steel Institute,” referred to the old maxim that some people were born great, others had achieved greatness, and others still had greatness thrust upon them. He was in the latter category that night. He had been connected with the steel trade for more years than he cared to remember, but that was the first occasion that he had had the distinguished honour of moving the toast of the Iron and Steel Institute.

In the speech that Sir William Ellis had made and in that of the President of the Board of Trade, there was, if he were

controversially inclined, sufficient material for an hour's oration. They were both wrong, but he was not going to try to put them right; it would be a waste of time, because after he had finished they would still hold the same opinions. In any case, the Iron and Steel Institute had been a great educational institute. When he looked back to his entrance into the steel trade in 1882 and contrasted what it was to-day with that early period, it appeared to him as if the age of miracles was not yet past. The younger members of the Institute in particular were very fond of reading papers on experiments that they had tried, and the criticisms of the older hands was not always couched in a kindly spirit. It seemed to him sometimes that the criticism pertained to the nature of the alleged sharpness of a Sheffield blade. The Institute was a sort of mutual competitive organisation for the diffusion of information. On reading some of the papers, and the criticisms of the great things that had been attempted, or accomplished, the thought had crossed his mind that there still remained secrets that they did not want to tell one another. It was the things they did not care about that they broadcast. That, notwithstanding, it was, he thought, to the chemists and the metallurgists in the trade that the great developments that had taken place were due. He was rather appalled at those developments, because they made for unemployment. As much steel was being made now as was made in the peak year of 1913 with, at any rate, 30 per cent. less men. That might mean cheapness in production, but it was one of the reasons why there were so many unemployed men in the steel trade and the iron trade to-day; and, as has been said by the President of the Board of Trade, as well as by Sir William Ellis, new markets were needed so that those unemployed men might be employed. How was that to be accomplished? Sir Frederick had been telling them about the long hours and the low wages on the Continent. He (Mr. Hodge) supposed the moral of that was that less wages should be paid and longer hours worked at home. But that was not what was wrong. They all knew as well as he did that, taking Belgium as an example—one of their competitors at the present moment—as a result of the treaty arising out of the Great War, reparation coal was being obtained at 10s. a ton. They knew what their own price was, and that if the men in the steel trade

were working for nothing, it would not make up the difference. Some other causes than that of wages and hours must be sought for as a remedy so far as the evils of foreign competition were concerned. So far as the steel trade was concerned—other trades could speak for themselves—there were no workmen who could do better than British workmen. He could remember when the first Talbot furnace started, and an American was brought over to teach the men how to work the furnace. That American failed to bring out the first charge, and the employer had to turn to his own men to do it. Steel smelting practice differed in America because they had not the difficulties to contend with that existed in Great Britain, with sulphur and phosphorus and various other foreign substances that had to be got out of the metal. An American steel smelter would be useless in this country; and those who knew anything about steel smelting knew that that was so.

Great developments had taken place in Great Britain as a result of the researches of the chemist and the metallurgist, and the Institute had been a sort of college for mutual education. The members exchange cost information and other matters, and that all meant the development of the trade. There could be no question, particularly since the war, of the great developments that had taken place so far as the Institute was concerned. It had played a great part so far as that development was concerned.

The President of the Board of Trade had referred to the sanctity of agreements and the necessity for good understanding. The iron and steel trade did not suffer from bad understanding. There was no industry in the world where there was such trust and confidence between workmen and employers as existed in the iron and steel trade. He was not going to claim the whole of the credit for the men, because both sides had played the game; the employers as a whole had honoured their agreements just as the men had. There had been no serious conflict in the steel trade since its existence. That was a great record—a record that both sides were entitled to be proud of. Differences had, of course, occurred; he himself had had differences with the President. Victory had been claimed on both sides.

Sir William Ellis thought that it was not quite the right thing that those representing the workmen should tell foreigners that

they ought to ask for shorter hours and better wages. They had had no compunction on that score; they had told them that many times. He himself had been telling them that for the last thirty years; and previous to the war on the Continent great progress had been made in that direction. It had been stated that Governments ought to have courage. The President of the Board of Trade had said so. Well, have courage; get the Government to ratify the working convention as to the hours of labour. If the British Government had given a lead the Continent would have followed. Continental nations as a rule looked to Great Britain to give a lead. None of the recent Governments had had any courage; they would not lead. He supposed they were waiting to follow. He had been in Cologne in the beginning of March at a Conference of the metal workers of the world, and told them what opinions prevailed at home. He was talking as much to the German industrialists as he was to the workmen, and he told them that the workmen in England were beginning to be tired of an open door as against a shut door. Another phrase he used—and he stood by it—that so long as there was an idle furnace in Great Britain he would permit no foreign steel to come in. A protectionist Government was now in power; had it the courage to follow his lead? He had told the German industrialists that in Great Britain the workers were beginning to get tired of the products arising in their country made under conditions as to wages and conditions of labour that did not obtain in Great Britain. At home there was what was known as the Fair Wages Contract Clause, and incidentally he had been responsible for it in 1908. By that means the good employer was protected against the employer who sweated his workmen or did not give decent conditions of employment. He said British labour was asking why the bad employer at home should be penalised and the foreigner who did not come up to the best standards encouraged. That was all he wanted. He did not want tariff reform, because that would help people who had obsolete plant. But the works that were up to date were entitled to get fair play, and he was anxious that they should have fair play.

Reference had been made to the dole. Why was it called the dole? It was because it was sparingly given. That was the dictionary definition of it. But workers and employers

amongst them had paid for it, and if the distribution of the dole, so-called, had been left in the hands of the trade unions, there would not have been any complaints about undesirables getting it, his experience being that the members of a trade union were very keen to see that no one who was not entitled to it should get it. They looked upon it as their money, and they would have looked after it.

It was impossible to have a great distribution of money, such as the unemployed benefit under the National Insurance Act, without having some bad cases. On the other hand, it was not possible to have a million and a quarter of men idle unless something was done by way of feeding them. Otherwise there would be revolution. It was not possible to have a great army of unemployed men starving without paying the penalty of that starvation.

The only remedy was work. How was it going to be obtained? It was the duty of the Government to do something whereby the resources of the nation could be utilised. He could suggest a lot of remedies. Instead of taking 6d. off the income-tax and leaving the super-tax man alone, he would have utilised that £36,000,000 in subsidising industry. The railways were subsidised, agriculture was subsidised, a whole host of things were subsidised, why not the steel trade as well? If it were going to make for employment, the nation as a whole would benefit. There was no toast he could propose with more zest or more pleasure than that of the Iron and Steel Institute. A great many of those associated with the Institute were his personal friends. He was just as interested in the welfare of the iron and steel trades as an employer. Their benefit and advantage was the benefit and advantage of the men that he represented. Harmonious relations had subsisted for forty years; he hoped he might live for another forty years to see even greater developments so far as the iron and steel trade was concerned. He wished continued success and prosperity to the Iron and Steel Institute.

The PRESIDENT, Sir FREDERICK MILLS, Bart., in responding, said he was sorry to have been compelled to take that office several years before he had expected, by reason of the fact that several of the Vice-Presidents who ought to have preceded him

having found themselves unable to accept office. Sir William Ellis was to be congratulated on having brought about the alteration of the rule which confined the occupancy of the Chair to one year only. He (Sir Frederick) could recall many eminent men in the iron and steel trades who would have made not only admirable Presidents, but who would have liked to have had the opportunity of being President of the Institute, had it not been for the two years' rule which prevented them ever having a chance of reaching the Chair.

Mr. The Institute was in a flourishing condition—a more flourishing condition than one might have expected, having regard to the conditions ruling in the industry to which it related. He knew of no one whom he would have preferred to propose that toast than his friend Mr. Hodge. It was forty years since he (Sir Frederick) had first made a steel ingot, and therefore it was about forty years since he came in contact with Mr. Hodge, and many a tussle had taken place in those early days. Having started with non-union labour he had been very uncertain as to whether he wanted trade union labour in the industry, but he was bound to say that Mr. Hodge in his early days, whatever he might have become since, was one of the most reasonable men he had ever had to deal with. There was one occasion, he supposed thirty-five years ago, when Mr. Hodge and he had a battle about the pit men at Stockton which lasted two years. He was thankful to say that he did not remember who it was who won on that occasion; it probably ended in a reasonable compromise and no great amount of harm was done. He congratulated Mr. Hodge on the marvellous way in which he had conducted his side of our industry, on the terms he had obtained for his men, and the extraordinary manner in which he had kept them. How long he would be able to keep them was entirely another matter.

That brought him rather to the point of controversy that had arisen that night. He had had strict injunctions to stick to his job in replying for the Institute. That would have been to discuss the questions of the future of the industry, the encouragement of the young men, the production of papers, the finances of the industry and of the Institute, and kindred subjects. But really, Sir William Ellis, the President of the Board of Trade—who had unfortunately been recalled to the House—and Mr. Hodge had

whetted his appetite in regard to those somewhat controversial matters. They all seemed to have different views as to what ought to be done with the industry. He (Sir Frederick) never had any doubt about it himself, and he ventured to believe his opinions might be worth expressing in a gathering of that kind. Surveying the industry as it existed to-day, all must marvel at the advanced condition of plant in every direction. It was obvious that there had been admirable British brains at work in building up the wonderful plants that the country now possessed. He agreed with Mr. Hodge that there was no iron worker in the world—and he had seen him in all parts of the world—to compare with the British iron worker and steel worker, not only in his craftsmanship but in his desire to do the best he possibly could. But when he saw, as he did recently in the North of England, those wonderful plants, upon which millions of new money have been spent, standing idle, he asked himself: "Why is it?" He was aware that to some extent that was the question that he had discussed at the Institute that morning; but confined in the walls of a scientific institution certain limitations had to be observed. In an after-dinner speech he imagined those limits might be wider, and he said without any hesitation whatever that those wonderful plants he had referred to were not having reasonable fair play. In America wages were higher; there was nobody idle in America; there were no idle plants in America; they were building up fresh ones. He had been in Sweden the previous week; wages in Sweden were as high or higher than they were at home. There was nobody idle in Sweden; the plants were not idle there. Of course, they were not idle in France and Belgium and Germany, because they were doing the trade that rightly belonged to Great Britain. It was high time that process was ended. He agreed with Mr. Hodge; as long as there was a furnace idle in Great Britain he would not allow an ounce of steel to come into it; nor would he allow, if he could, an ounce of steel to go into any part of the British Empire unless it were British made. The British Empire was big enough to trade with itself; it could produce everything that was wanted: it had all the raw materials it required. Goodness knows many white men in the Empire were anxious to trade with white men in the home country. The Empire was big enough; it

should be ring-fenced and its trade preserved for itself. If that were done every other nation in the world would speedily seek to come to terms with it. (Loud applause.)

THE GUESTS.

Sir W. PETER RYLANDS, Vice-President, in proposing the toast "The Guests," said that amongst so many distinguished guests by whose presence the Institute was honoured that evening, there were many who were intimately connected, either directly or indirectly, with the iron and steel industries or the coal industry which naturally constituted a temptation to dwell, as other speakers had done, for a few moments upon the commercial point of view. Many of those present were probably regular attendants at the Birmingham Quarterly Meetings, which afforded pleasant opportunities of meeting business friends from all over the country, and also afforded an opportunity of discussing the trade outlook. In times of prosperity he had always noticed that the Birmingham meeting was followed by even more marked optimism; but, conversely, if trade were bad and the outlook depressing, the opportunity for indulgence in expressions of mutual sympathy sent them all home in a condition of black despair. He was credibly informed that the condition of the iron and steel industry, and of the coal trade as well, at the present time was not everything that could be desired. If that were the case, the danger of discussing those matters with so many who were interested in the subject involved a similar risk of accentuating those difficulties.

His friend Mr. Hodge had given an account of some remedies that he would propose and which he was satisfied would cure those troubles; the President himself had also given an indication; and he (Sir Peter) was personally in possession of another sovereign specific. Failing the adoption of any of those remedies, there might be others. Sir Ernest Hatch was one of the guests. He was the Treasurer and Chairman of University College Hospital, and was anxious to appeal, and he hoped with success, to the iron and steel industry for financial support for those interests which he had so much at heart. It had occurred to him (Sir Peter) that perhaps in return Sir Ernest Hatch might apply his medical knowledge to minister to the ailments under which the industry was suffering,

failing which, perhaps he would be able to give them a recommendation to a hospital for incurables. Sometimes in the Press letters were seen from persons whom those present as technical manufacturers might be inclined to regard as irresponsible, suggesting that any difficulties from which the industry, and British manufacturers generally, were suffering arose from their own utter incompetence. Up to a period not so very long ago the business enterprise and acumen of British manufacturers was Britain's pride, and was held accountable for the great commercial development and industrial prosperity of the country during the past century. Whatever their detractors may say, the iron and steel trade may take comfort in the conviction that it was not very far behind our forefathers, and not less endowed with those faculties of enterprise and commercial ability which in their case, at all events, had been so highly extolled. At all events particular pride could be taken in the existence of the Iron and Steel Institute, a body with a long and honourable history which had contributed in no small measure to the technical advancement of the industry. They were proud to assure their guests that while they were not unmindful of the necessity of those commercial qualities of push and go, they ranked very high the importance of research on the technical side, and hoped that the exchange of views for which that evening's gathering had afforded such a pleasant opportunity would enable them to leave with a sense that those engaged in the industry were lacking neither in vigour nor enterprise, whether commercial or technical, in seeking to maintain the traditions of their great industry.

The toast was enthusiastically honoured.

Mr. EVAN WILLIAMS (President of the Mining Association of Great Britain), in responding to the toast, said his task was one which involved no small amount of responsibility as the guest who had to reply for his fellows on an occasion of that kind had to undertake to represent the views of a number of gentlemen with whom to a very large extent he was not personally acquainted. He thought he could safely say that he correctly interpreted the sentiments of his fellow-guests in thanking their hosts for the excellence of the entertainment provided, both solid and liquid, and if he included gaseous, he was to be distinctly understood to

refer strictly and solely to the tobacco smoke and not to the excellent speeches to which they had listened with pleasure.

As regards the particular industry with which he was associated—an industry which, under some unlucky star, he was born into, in which he had been forced to live pretty well all his life, and from which he had some dim and distant recollections of having at some time or other obtained a kind of living—he was afraid that anything he might truthfully say that evening would be hardly appropriate to a convivial gathering of that kind. It was a very painful subject. He could draw a picture of the miseries of coal-owners which would bring tears of sympathy even to the eyes of a London householder. He would, however, spare them that: it was for other occasions and for other places. As a guest of probably the best customer of the coal trade, the iron and steel trade, it would be very desirable to say something comforting and cheerful; but a somewhat embarrassing respect for the truth and a sense of responsibility imposed upon him a measure of reticence in regard to that. That reticence did not appear to appeal quite so much to his friends on the other side of the industry, judging from the flood of rhetoric which was heard during the May Day celebration. However, in speaking of the coal trade it was generally referred to as the basic industry of the country. He had said so himself; he had said so to the President of the Board of Trade when he wished to be impressive in taking deputations to him; and he was rather glad perhaps that he was not there at the moment when he (Mr. Williams) had to confess that perhaps on the whole it was not accurate to say that the coal trade was the basic industry of the country. Coal was a somewhat modest ancillary to other industries of the country, as one of the sources of energy which they used. Coal was produced purely and simply in order to be burned, and when it had done its job it disappeared, leaving behind it only its ashes, which he thought perhaps some of those present would say were rather too bulky in quantity at certain times. It was more correct to say that the iron and steel industry was the basic industry of the country. Iron and steel entered permanently, or more or less permanently, at any rate, into every industry and into every structure in that and in other countries. It even entered into the houses that were now to be made by Lord Weir. It was to a greater volume of trade and a greater prosperity of the iron and

steel industry—and he meant the home iron and steel and not the iron and steel industries of other countries—that they had to look for an increase in the prosperity not only of the coal industry but of every other industry. He was not desirous of minimising in any way the importance of the coal trade. Coal, without a doubt, was a valuable national asset ; but it was an asset which was of value only when it could be realised, and realised by its production at a cost at which it could be used to advantage by the other industries and exported abroad. There was not the slightest doubt that British coal was the best coal in the world, and we had in the past been rather prone to look upon it as being absolutely essential to the rest of the world. There was reason to fear that nowadays, instead of being an absolute necessity, it was becoming a luxury which other nations could not afford to pay for. Foreign customers could only pay for British coal if they could get it at a price at which it was the most economical for them to use. They could not be expected to buy it for love of us, or in order to enable us to enjoy an amount of leisure which they themselves abroad, and those who competed with us in particular, seemed to be content to do without.

He did not wish to enter upon any controversy, particularly with his friend Mr. Hodge. He had not had the pleasure of meeting him in negotiations in the past, and he hoped it might not be his lot to meet his doughty opposition in any particular instance in the future. But while all were, he believed, desirous of maintaining a good standard of living at home, and giving the best social services possible, granting pensions to all who deserved them, and having the best possible conditions in industry, they had to be careful lest in the attempt to attain those objects they killed and destroyed the very means by which those objects could be attained. It was no good having good conditions in the industry unless work could be provided for that industry to be carried on. There were great difficulties to meet and a very serious situation, and he felt quite certain that the salvation of the industry and the solution of the problems were to be found at home and not abroad. It was for all of them to put their backs into their work, and by a similar effort to that by which they won the war, win back peace and prosperity to the industries of their country.

OBITUARY.

ADOLPHUS OTTO BACKERT died from heart failure on April 24, 1925, at his residence, Lake Avenue, Lakewood, Ohio. He was born in Cleveland in 1876. He was graduated from the Central High School, and for several years attended the Western Reserve University. After serving as political reporter on the *Cleveland World*, he became associate editor of *Iron Trade Review* and the *Foundry*. From 1906 to 1908 he acted as Western editor of the *Iron Age*, with headquarters at Chicago. Subsequently he became editor of the *Foundry* and also engineering editor of *Iron Trade Review* from 1908 to 1913. In 1913 he became vice-president and general manager of the Penton Publishing Co., and in 1924 he was elected president and general manager of that company. He was well known throughout the foundry industry not only in the United States, but also in Europe and Australia. He rendered valuable services to the American Foundrymen's Association, serving as secretary-treasurer, president, and director, raising that Association to a position of world-wide eminence among technical organisations. He was secretary and later hon. member of the Foundry Supply Manufacturers' Association, and was also secretary of the Foundry Equipment Manufacturers' Association from its inception to the time of his death. He conceived the idea of the Allied Metals Congress held in Milwaukee in 1918. He visited Europe in 1919 to invite foundrymen to the Inter-Allied Foundrymen's Convention and Exhibition in Philadelphia. He was the writer of a number of authoritative books and papers upon foundry practice and iron and steel activities, and was also editor of the "ABC of Iron and Steel." He was a member of numerous technical Associations, including the American Iron and Steel Institute, American Institute of Mining and Metallurgy, and the American Society for Testing Materials. He was elected a member of the Iron and Steel Institute in 1919.

JOHN H. BARNBROOK died at his residence, Highbury, Bearsden, on March 27, 1925, at the age of fifty-seven. He was steelworks manager of the Eclipse Rolling-Mills of Frederick Braby & Co., Ltd., Glasgow, a position he had held since the No. 1 rolling-mill plant was started 16½ years ago. He received his earlier training in the steel sheet rolling industry with E. Parkes & Co., Ltd., at West Bromwich, after which he spent some years as mill manager at Messrs. Lysaght's works at Newport, and afterwards at Messrs. Shaw's works, Huyton Quarry. He was elected a member of the Iron and Steel Institute in 1917.

HERBERT SANDERSON BLECKLY died at his residence, Limassol, Hale, Cheshire, on February 20, 1925, in his seventy-seventh year. He was the fourth son of the late Mr. Henry Bleckly of Altrincham, and for fourteen years was a director of the Pearson and Knowles Iron Co., Ltd. He was elected a member of the Iron and Steel Institute in 1878.

FREDERICK CLEEVES died on January 10, 1925, at the age of eighty-two. He was a well-known figure in the coal industry, and was one of the founders and pioneers of the South Wales anthracite coal trade. He was elected a member of the Iron and Steel Institute in 1898.

FREDERICK CRABTREE died on February 14, 1925, at St. Petersburg, Florida. He was born in Bramley, Yorkshire, in 1867. He attended the Massachusetts Institute of Technology and graduated with the degree of B.Sc. in chemistry in 1889. He afterwards served as chemist with the Illinois Steel Company, and with the National Tube Co. from 1890-1900. He was superintendent of the Western Steel Co. for two years, and later superintendent of the blast-furnaces of the Colorado Fuel and Iron Co. until 1904. He then became professor of mining and metallurgy at the Colorado College. Leaving that position, he went to Pittsburg and joined the staff of the Carnegie Institute of Technology, and served as head of the department of Mining and Metallurgical Engineering since 1906. He was a member of the American Institute of Mining and Metallurgical Engineers; American Iron and Steel Institute; American Electrochemical Society; American Society for Steel Treating; and the Engineers Society of Western Pennsylvania. He was elected a member of the Iron and Steel Institute in 1913.

CARL DELLWIK died on December 12, 1924, at the age of sixty-two. He was prominently associated at the beginning of the present century with the manufacture of water-gas, and took a prominent part in the development of the Dellwik-Fleischer process, which he described in a paper before the Iron and Steel Institute, 1900. He was a member of the Institution of Mechanical Engineers, and was elected a member of the Iron and Steel Institute in 1900.

ELWOOD HAYNES died at Kokomo, Indiana, on April 13, 1925. He was born at Portland, Indiana, in 1857, and was educated at the Worcester Polytechnic Institute and the Johns Hopkins University. In 1887 he began his work in the development of the automobile, and some seven years later constructed and operated an automobile capable of a speed of seven or eight miles an hour and running several miles without a stop. This was the first car built in the United States, and is now on exhibition at the Smithsonian Institution, Washington. He was particularly well known for his introduction and development of stellite, a high-speed metal-cutting material, which was numbered

among his discoveries of alloys of cobalt, chromium, molybdenum, and tungsten. In 1922 he was awarded the John Scott medal for his discoveries in stainless steel. He was an hon. member of the American Society for Testing Materials, and a member of numerous engineering and scientific societies, through which he contributed to the progress of engineering in a very material way. He was elected a member of the Iron and Steel Institute in 1911.

JOHN MACDONALD HENDERSON died at his residence, Queen's Road, Aberdeen, on February 19, 1925. He was chairman and managing director of the firm of J. M. Henderson & Co., Ltd. He gained his earlier experience in the business established by his late father, to which he succeeded. He specialised in hoisting and transporting machinery, in Blondin cable-ways for mines and quarries, and in cranes and stone-work appliances. He was elected a member of the Iron and Steel Institute in 1921.

JOHN HOUGHTON died at his residence, Foxley Lodge, Lymm, Cheshire, on December 15, 1924, at the age of seventy-four. He was the eldest son of the founder of W. D. Houghton & Co., Ltd., wire manufacturers, of Sankey, Warrington. He was managing director of that company and chairman of Hobson, Houghton & Co., Ltd., of the Don Steelworks, Sheffield. He was elected a member of the Iron and Steel Institute in 1873.

RALPH T. HUGHES died on April 5, 1925, at Saltburn. He was principal of the firm of Hughes, Bolekow & Co., Ltd., shipbreakers. The firm has large establishments on the Tyne and at Blyth, and has broken up some of the most famous battleships in the British Navy. He was elected a member of the Iron and Steel Institute in 1912.

JAMES GRAHAM JENKINS died at his residence, Airedale, Cambuslang, on February 9, 1925, at the age of seventy-five. He was educated in Glasgow, and after leaving the University became business manager to the Ditton Brook Ironworks, Lancashire. In 1874 he received the appointment of manager of the Iron Mines at Goldames, near Bilbao. Six years later he returned to Glasgow and joined his father in the iron and steel business. He was among the first to introduce Cumberland ore and Spanish rubio ore into Scotland. He was also identified with the trade in West Cumberland hæmatite pig iron from the time of the introduction of the open-hearth process into Scotland. In 1901 he acted as Local Hon. Secretary of the Glasgow Meeting of the Institute, and contributed greatly to making the meeting a brilliant success. He was an original member of the West of Scotland Iron and Steel Institute, and was elected a member of the Iron and Steel Institute in 1872.

GEORGE BERNARD REYNOLDS was born in 1853. He was educated at the Royal Indian Civil College, Coopers Hill, and was one of the first to graduate from that establishment. In 1875 he joined the Public Works Department (Railways) in India. During his work there it became necessary to develop a coal-mine at the end of a branch line of which he had charge, and this resulted in his being put in charge of the mine also. Becoming interested in mining, he took the opportunity of a long leave to study the subject and to obtain a colliery manager's certificate; and thus, on his return to India, he was enabled to devote his energies to coal-mining. It was not until he retired at a comparatively early age from the Indian Public Works Department that he turned his attention to petroleum, and his first oil-field development work was in the Island of Madoura, off Sourabaya, in Java. Unfortunately, the structures tested there were very steep and by no means favourable, and no real success was attained. Going on to Persia as general manager for the Darcy Exploration Syndicate, he spent several years at Kast-i-Shirin, Chardine, and Marmatain, taking charge of all the drilling operations in those fields. Those were very difficult times in Persia; the nomadic population was actively hostile, and the syndicate's property—not to mention the lives of the staff—was often in jeopardy. But for Mr. Reynolds' tactful and diplomatic handling of dangerous situations, it may safely be said that the exploration work would have been impossible. No one who was not with Mr. Reynolds at that time can know how nearly the work of the Darcy Exploration Syndicate came to an end. But, with the location of the first tests of the Maidan-i-Naftun field, the tide turned; the formation of the Anglo-Persian Oil Company followed quickly on the successful results of the first wells.

Mr. Reynolds afterwards turned his attention to Venezuela in the interests of the Venezuelan Oil Concessions, Ltd., and once again his efforts were handsomely rewarded. Few British technologists can have been associated with such outstanding successes in developing new fields as those of the Anglo-Persian Oil Company and the Venezuelan Oil Concessions; and these successes are due, to a greater extent than may be realised by many, to the sterling work of Mr. Reynolds. At a later date he joined the Technical Staff of the British Controlled Oil Company, and was actively engaged in pioneer work up to the time of his death.

He was a member of the Institution of Civil Engineers, the Institution of Mining Engineers, and was elected a member of the Iron and Steel Institute in 1885.

JOHN EDWIN ROGERSON, of Mount Oswald, Durham, died on March 23, 1925, at the age of sixty. He was the eldest son of the late Mr. John Rogerson, of Croxdale Hall, Durham. He was educated at Durham School, and Trinity College, Cambridge, where he took degrees of B.A. and M.A. After leaving Cambridge he entered the firm of John Rogerson, Ltd., at their Stanners Close Steelworks, Walsingham,

where he was articled to his father. From that time he began his extensive interests in many ironworks and colliery enterprises in the northern counties. He was one of the founders of the North Walbottle and Seaton Burn Colliery Companies. He served on the Board of Directors of many companies, including the Weardale Steel and Coal Co., Ltd.; Cargo Fleet Iron Co., Ltd.; South Durham Iron and Steel Co., Ltd.; and Cochrane & Co., Ltd. He represented the Barnard Castle Division in Parliament in 1922-23. He was elected a member of the Iron and Steel Institute in 1890.

EDWARD WILLIS SWAN died on March 9, 1925, at his residence, High Field, Crown Hill, Middlesbrough. He was one of the oldest and best-known figures in the iron and steel trade on Tees-side. With his brothers he founded the firm of Swan Brothers in 1865. The firm opened out an extensive connection with Scotland, and laid the foundation of what was to become one of the principal areas for the consumption of Cleveland iron. He was elected a member of the Iron and Steel Institute in 1873.

JOSEPH TORBOCK died in April 1925, at the age of seventy-three. He was closely associated with the iron trade of Tees-side. He was chairman of the Forsett Limestone Co., Ltd., and the North African Mining Co., Ltd., and a director of the Linthorpe Dinsdale Smelting Co., Ltd., and the Indian Manganese Co., Ltd. He was elected a member of the Iron and Steel Institute in 1891.

ROUGHSEGE WALLWORK died on January 14, 1925, at the age of seventy-two. He was chairman of Henry Wallwork & Co., Ltd., Manchester, and was the nephew of the founder of the firm. He was a member of the Institution of Mechanical Engineers, and was elected a member of the Iron and Steel Institute in 1900.

SECTION II.

*NOTES ON THE
PROGRESS OF THE HOME AND FOREIGN
IRON AND STEEL INDUSTRIES.*

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IRON ORES

AND OTHER METALLIFEROUS ORES USED IN THE IRON AND STEEL INDUSTRY.

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I.—GEOGRAPHICAL DISTRIBUTION OF ORES.

(Arranged in alphabetical order under Countries.)

Alaska.—A. H. Brooks, *Mineral Resources of Alaska* (United States Geological Survey, 1924, Bulletin No. 755). This bulletin summarises the results achieved during the year 1922 in the investigation of the mineral resources of Alaska.

Albania.—E. Nowack, *The Mineral Occurrences in Albania* (Montanistische Rundschau, 1924, vol. 16, No. 24, pp. 695–697). Occurrences of coal, iron ore, manganese ore, chromite, and hydrocarbon substances are described.

Australia.—L. F. Harper, *Aluminium* (New South Wales Geological Survey, 1924, Bulletin No. 8). The occurrence of alunite and bauxite in New South Wales is dealt with. The only workable deposit of alunite yet found is at Bullah-delah, and geological investigations have been restricted as regards this occurrence. As regards bauxite, much more work is necessary before it will be possible to give a detailed account of each occurrence. A list is given of complete and partial analyses of trial samples obtained. Some of the analyses indicate that true bauxite occurs in New South Wales, and attention is drawn to the possible value of the deposits from which these analyses were obtained.

Canada.—E. S. Moore, *Some Geological Conditions Controlling the Formation of Iron Deposits in Canada* (Bulletin of the Canadian Institute of Mining and Metallurgy, Mar. 1925, pp. 209–219).

J. L. Tanton, *Iron Formation at Gravel Lake, Thunder Bay District, Ontario* (Canada, Geological Survey, 1923, Summary Report, Part C1, pp. 1–5).

China.—O. R. Kuhn, *China's Ore Reserves* (Iron Trade Review, Jan. 15, 1924, vol. 76, pp. 215–219). The iron ore deposits of China are briefly described, and statistical information is given of the iron and steel industry. Much of the information given is taken from the report by F. R. Tegengren. (See this Journal, 1924, No. II. p. 327.)

England.—B. Smith, *Iron Ores—Hæmatites of West Cumberland, Lancashire, and the Lake District* (Geological Survey, Special Reports on Mineral Resources of Great Britain, vol. 8, London, 1924). The present report is a second edition of a comprehensive report issued in 1918. (See this Journal, 1919, No. II. p. 458.)

W. McDonald, *West Cumberland Hæmatite Deposits* (Iron and Coal Trades Review, Mar. 13, 1925, vol. 110. p. 434). The origin of these deposits is discussed and the possibilities of new ore bodies are considered.

India.—E. W. T. Slater, *Manganese Mining in India* (Engineering and Mining Journal-Press, Dec. 27, 1924, vol. 118, pp. 1017–1018). The occurrence of manganese ore in India and the methods of extraction are described briefly.

Newfoundland.—D. J. Davies, *Mining and Metallurgy in Newfoundland* (Bulletin of the Institution of Mining and Metallurgy, Dec. 1924). Iron ore occurs extensively at Bell Island. The actual amount of ore in sight has been estimated by various authorities at about 3,500,000,000 tons. The three ore-beds of commercial value on the island are known as the Upper, Scotia, and Dominion seams. These three are being worked at the present time and have supplied all the ore so far mined in this district. The ore is reddish-brown hæmatite of a fine-grained oolitic texture. Adjacent to these deposits at Bell Island, around the shores of Bay de Verde, there are many indications of the occurrence of iron ore. On the west coast of the island are large deposits of titaniferous magnetites in the St. George's district, and there are good indications of a big deposit of altered hæmatites, containing from 60 to 66 per cent. of iron, at Stephenville.

J. B. Gilliatt, *Folding and Faulting of the Wabana Ore Deposits* (Bulletin of the Canadian Institute of Mining and Metallurgy, Dec. 1924, pp. 895–913).

United States.—O. R. Kuhn, *Iron Ore Available for United States* (Iron Age, Nov. 6, 13, 1924, vol. 114, pp. 1204–1205, 1248–1249, 1285–1287). An analysis is made of the probable requirements of the United States for iron ore for the next 300 years, the total being approximately 65,000 million tons. A short survey is also given of the more important iron ore reserves of the world.

W. R. Crane, *Red Iron Ore Mining Methods in the Birmingham District* (Paper read before the American Institute of Mining and

Metallurgical Engineers, Feb. 1925). A description is given of the methods of iron ore mining in the Birmingham district of Alabama. The district produces approximately 10 per cent. of all the iron ore of the United States.

F. C. Schrader, *Molybdenite in the Rocky Bar District, Idaho* (United States Geological Survey, 1924, Bulletin No. 750-F.). The author describes several deposits of molybdenite in Elmore County, Idaho.

C. P. McCormack, *Economics of the Cuyuna Manganiferous Iron Ores* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). These iron ores can become a principal source of manganese for the iron and steel industry of the United States, provided metallurgical methods as a whole are adjusted so as to use run-of-mine ore. The function of manganese in steel-making and the adaptability of these ores are discussed.

C. Zapffe, *Manganiferous Iron Ores of Cuyuna District, Minnesota* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). Although the Cuyuna district produces mostly high-phosphorus iron ore, the annual production of manganiferous iron ore is increasing rapidly, and this class of ore bids fair to become the principal product of the district. The principal characteristics of the ores and their deposits, and the possibilities in future developments of the deposits, are discussed. Typical analyses of ores from different deposits are tabulated.

G. A. Thiel, *Commercial Possibilities of the Magnetite Slates of the Cuyuna Range* (Engineering and Mining Journal-Press, Nov. 8, 1924, vol. 118, pp. 735-738).—The author outlines the occurrence of the magnetite-bearing formations of the Cuyuna Range, their relations to the intrusive igneous rocks of the region, and the bearing of the micro-structure of the ore on the possibility of magnetic concentration.

J. W. Gruner, *Contributions to the Geology of the Mesabi Range* (Minnesota Geological Survey, 1924, Bulletin No. 19). This bulletin has special reference to the magnetites in the iron-bearing formation west of Mesabi.

E. F. Burchard, *Bauxite in North-Eastern Mississippi* (United States Geological Survey, 1925, Bulletin 750-G., pp. 101-146). The character of the bauxite deposits in north-eastern Mississippi is described, and the uses and requirements of bauxite are outlined.

Mineral Resources of the World.—A. Redlich, *The Iron Ore Resources of the World* (Berg- und Huttenmännisches Jahrbuch, 1924, vol. 72, No. 4, pp. 1-34). The author gives a brief review of the iron ore resources of the chief countries of the world, with a table showing the production, exports, and imports, and pig iron production of each country. Great Britain is credited with larger reserves of iron ore than any other country except the United States.

W. G. Rumbold, *Bauxite and Aluminium* (Imperial Institute, Monographs on Mineral Resources, London, 1925). A general account is given

of the occurrences and commercial utilisation of bauxite and aluminium, particularly in the British Empire. The report also includes a list of references to literature on the subject. The following reports dealing in the same manner with bismuth ores and antimony ores have also been published:

R. N. Allen, *Bismuth Ores*.

E. Halse, *Antimony Ores*.

F. L. Hess, *Molybdenum Deposits* (United States Geological Survey, 1924, Bulletin No. 761). This report consists of a review of the world's chief molybdenum resources.

F. L. Hess, *Marketing of Vanadium Ores and Metal* (Engineering and Mining Journal-Press, Nov. 1, 1924, vol. 118, pp. 694-698). A description is given of the various types of vanadium deposits. Analyses of the chief grades of ferro-vanadium marketed in the United States are also included.

Structure of Minerals.—L. Pauling and S. B. Hendricks, *The Crystal Structures of Hämatite and Corundum* (Journal of the American Chemical Society, Mar. 1925, vol. 47, pp. 781-790). The crystal structures of hæmatite and corundum have been determined through the use of Laue and spectral photographs interpreted with the aid of the theory of space groups.

J. S. Vanick, *Microstructural Features of Several Meteorites* (Transactions of the American Society for Steel Treating, Feb. 1925, vol. 7, pp. 171-196). The structural features of several meteorites which represent massive bodies of single-grain high-nickel iron are described. An effort is made to correlate these features with their composition and with certain facts known to physical metallurgy.

II.—PREPARATION OF ORES.

Flotation of Minerals.—A. Fischbacher, *The Flotation of Metallic Minerals* (Revue de l'Industrie Minérale, Mémoires, Nov. 15, 1924, pp. 523-532). Theory and general practice of flotation, with data as to the actual yields obtained with different minerals when subjected to such processes.

Concentration of Ores.—H. Müller, *Concentration of the Dogger Ores of Upper Frankenland* (Stahl und Eisen, Mar. 19, 1925, vol. 45, pp. 423-426). At Pegnitz there occurs a considerable deposit of so-called Dogger ores for which a concentrating process has been developed, enabling the ores to be concentrated up to 50 per cent. of iron. Some 30 million tons of ore are available with an iron content from 31·5 to 44 per cent. The process consists of roasting in kilns, and the resulting product contains iron 46 to 50, silica 17 to 20, alumina 8, lime and

magnesia together 2.5, phosphorus 0.3, and sulphur 0.5 per cent. It is some two or three years since the ores began to be utilised, but operations are suspended at present on account of high railway freights.

W. Luyken, *The Degree of Efficiency of an Ore-Concentration Process* (Mitteilungen aus dem Kaiser-Wilhelm Institut für Eisenforschung, 1924, vol. 6, pp. 17-20). Calculations are made to determine the highest degree to which an ore can be concentrated compatible with a reasonable rate of output of concentrates and yield of metal.

Screens.—C. Ratel, *The Standardisation of Metallic Meshes and the Unification of Crushing Diagrams* (Chimie et Industrie, July 1924, vol. 12, pp. 16-30). Inextricable confusion exists through the existence of different units of measurement as applied to sieves in France, America, England, and Germany. The mesh of French screens is referred to as the number of linear divisions in a French inch, which is 27 millimetres. Such divisions are called "maille." Concurrently with this system an English inch (25.4 millimetres) is also employed, the linear divisions of which are called the "mesh." The ratio of the maille to the mesh thus becomes 1:1.063, and confusion occurs at the very start. Further, the number of holes (mailles or meshes) in a linear unit determines the description of a given screen, without taking at all into consideration the diameters of the wires of which it is made. Hence, merely stating the number of holes per linear unit conveys absolutely no definite information as to the actual size of the holes, or of the order of size of the resulting particles sieved through them. This has been long recognised, and systems of a more accurate and scientific description have been put forward. They include the series of the Institution of Mining and Metallurgy; the Hoover Series; the Rittinger, the Richards, and the Tyler. A new standard series is put forward for French sieves, and the question of what gauge wires should be adopted is considered, comparative tables of the various international wire gauges being given. The application of various sieves to given materials and the comparative efficiency of crushing machines are likewise discussed.

Handling Iron Ore.—L. Rocault, *The Handling and Preparation of Iron Ores at the Trinec Works, Czechoslovakia* (Revue de l'Industrie Minérale, Mémoires, Mar. 1, 1925, pp. 100-106). The Trinec works are near Teschen, in Silesia, and obtain their coal, from which excellent metallurgical coke can be made, from the Ostrau-Karwin coalfields, a few miles away. The ore-supply is, however, derived by waterways from Scandinavia, and shipments have to be suspended from November to May each year, owing to the freezing over of the Oder. The company, which is deeply convinced of the necessity for maintaining burdens for its blast-furnaces as chemically and physically uniform and homogeneous as possible, has been forced to provide very large ore storage accommodation, and has, moreover, installed appliances for breaking the ore into pieces of uniform size and for sintering the fines. The ore bunkers are

two kilometres distant from the blast-furnaces, to which the ore is transported on the Stahler system. The ore park has been designed on an extensive scale, and the sequence of operations from the arrival of the ore to its despatch to the furnaces is described in detail, with plans and illustrations. The total storage capacity is 300,000 tons. The fines are agglomerated in a rotary furnace made by Schmidt of Copenhagen. There are two such furnaces, each 47 metres in length and 2·40 metres in diameter. 500 tons of fines are handled per day (three shifts) and 420 tons of agglomerates obtained, at a fuel expenditure of 12 to 14 per cent. of the weight of agglomerated ore produced. Only a foreman and seven other workmen are required to handle the ore stocks, and the labour and other costs in the agglomeration section amount to no more than 12 to 13 francs per ton. The practice at the furnaces is also exceptionally good. On white pig iron burdens only 740 kilogrammes of coke is used per ton of pig iron produced. The ores used are not easily reduced, as might be assumed from these figures. On the other hand, they contain 55 per cent. of iron. The good yield is attributed solely to the physical conditions of the burden, from which alike both the fines and the large lumps are removed.

REFRACTORY MATERIALS.

Magnesite.—G. W. Bain, *Types of Magnesite Deposits and their Origin* (Economic Geology, 1924, vol. 19, pp. 410-433). Magnesite deposits can be divided into four types : (1) Magnesite as sedimentary rock ; (2) magnesite as an alteration from serpentine ; (3) magnesite as a vein filling ; (4) magnesite as a replacement of limestone. Magnesite from sedimentary deposits or from deposits in serpentine is usually very uniform and free from objectionable constituents. Magnesite from fissure veins is very ferruginous, due to the presence of iron carbonates, while that from replacement deposits is variable and requires very careful sampling.

H. Nishihara, *An Enormous Magnesite Deposit in Manchuria* (Engineering and Mining Journal-Press, Mar. 21, 1925, vol. 119, pp. 488-489). A description is given of a large deposit of magnesite in Manchuria, three miles south-east of Tashihchiaio, which is being worked by the South Manchuria Mining Company.

Silica.—L. F. Harper, *Silica* (New South Wales Geological Survey, 1924, Bulletin No. 10). An account is given of the recorded deposits of quartzite in New South Wales, together with particulars of silica-brick plants in the State and a general outline of the manufacture of silica bricks.

Preparation, Properties and Tests of Refractories.—P. Dressler, *Adaptation of Tunnel and Car Kilns to Firing Refractories* (Journal of American Ceramic Society, Jan. 1925, vol. 8, pp. 43-54). In firing high-temperature refractories the chief difficulty has been to obtain a sufficient output from a tunnel kiln of reasonable length. In the cross-fire regenerative kiln this has been accomplished by greatly increasing the cross-section. The kiln consists of a series of short kilns, each of which can be regulated and controlled independently. Burners are fitted on both sides of the kiln, which are used alternately, the draught being switched at intervals from one side to the other, causing the gases to pass transversely from side to side alternately.

R. C. Gosreau, *Bonding High-Temperature Refractories* (Chemical and Metallurgical Engineering, Nov. 3, 1924, vol. 31, pp. 696-698). The author has tabulated the properties of a number of bonding materials for high-temperature refractories, in order to aid the electric furnace operator in the selection of material for patching, fettling, and the making of monolithic linings.

W. Steger, *Capacity of Refractory Materials to Resist Changes of*

Temperature (Stahl und Eisen, Feb. 19, 1925, vol. 45, pp. 249-259). To test the capacity of refractory materials to withstand changes due to variations of temperature, specimens were heated to the following temperature ranges: 15-300°, 300-500°, 500-600°, 600-750°. They were then quenched and the loss of weight or decrease in mechanical strength was measured. The coefficient of thermal resistance was determined by measurement of the tensile strength, coefficient of expansion, modulus of elasticity, heat conductivity, specific weight, and specific heat. The measurement of the coefficient of expansion in the four above-mentioned temperature ranges was also made in order to determine the volume changes in fireclay and silica bricks conditioned by the allotropic changes of the crystallised forms of silica. The quenching tests gave the following relative values for the sensitiveness of various refractories to changes of temperature, taking that of magnesite = 100.

Carborundum bricks with clay binder	.	.	.	.	.	2
Bauxite bricks	.	.	.	.	.	13
Zirconia bricks	.	.	.	.	.	16
Fireclay bricks	.	.	.	.	.	3 to 30
Chromite bricks	.	.	.	.	.	42
Silica bricks	.	.	.	.	.	75
Magnesite bricks	.	.	.	.	.	100

The fireclay bricks tested contained alumina and silica in the proportion of about 1 to 2, and the great differences in their resistance to temperature changes are shown to be due to differences in the quantity, grain-size, and crystal form of the allotropic modifications of silica.

H. S. Houldsworth and J. W. Cobb, *The Behaviour of Clays, Bauxites, &c., on Heating* (Transactions of the Ceramic Society, 1923-24, vol. 23, pp. 281-292). The shrinkage of clays is not a continuous process, but one which takes place in a number of stages, each stage being completed at a definite temperature. Shrinkages of considerable magnitude occur at almost the same temperatures with the different clays, namely, 530° C. (except with ball clay), 880°, 950°, and 1030° to 1060° C. Changes in density also occur at these temperatures. Kaolin and fireclays show a distinct heat absorption at 500° to 530°, and a heat evolution at 950°. It seems likely that the changes observed on heating clays may be due both to changes in the chemical constitution of the molecules of the clay and to a rearrangement of those groups of molecules which form the unit of crystal structure of the clay.

G. E. Merritt, *Thermal Expansion of Fused Quartz* (Journal of American Ceramic Society, Nov. 1924, vol. 7, pp. 803-808). The coefficient of expansion of fused quartz from very low temperatures has been studied. Specimens of fused quartz at -200° C. were found to contract as the temperature gradually rose to -70° C. Above -70° expansion sets in, the coefficient of expansion increasing gradually until at room temperature it becomes 0.5 μ per metre per degree, and this value is maintained almost unchanged to 1000°. At about 1000° the expansion increases, reaching a maximum of almost 1.2 μ per metre per degree

at 1100° C. At 1140° the specimens softened. If held constant above 1020° the fused quartz continues to expand but the change in dimensions is not permanent.

W. Hugill and W. J. Rees, *The Influence of Phosphoric Acid and Phosphates on the Rate of Inversion of Quartz in Silica Brick Manufacture* (Transactions of Ceramic Society, 1923-24, vol. 23, pp. 304-306).

S. S. Cole, *European Silica Refractories* (Journal of American Ceramic Society, Jan. 1925, vol. 8, pp. 55-58). An investigation was made on silica bricks and shapes made in Europe and on the ganister used in their manufacture, and tests were made on the best grades of bricks. It is generally concluded that, with few exceptions, silica brick manufactured in Europe is not satisfactory for use in coke-oven construction on account of its low fusion point, and that it is underfired and not well bonded.

E. Steinhoff, *Investigation of Silica Bricks* (Stahl und Eisen, Oct. 16, 1924, vol. 44, pp. 1277-1283). The results of an investigation on three types of silica bricks are reported, the tests having been carried out at the laboratory of the Dortmunder Union. Each single brick supplied the material for a complete set of tests which comprised a complete analysis, and the determination of the specific weight, melting point, microstructure, porosity, expansion, and resistance to crushing at high temperatures. The influence of a more or less complete transformation of the quartz on the durability of bricks was also studied. Bricks in which the quartz was not completely transformed in manufacture improved in crushing strength after eight days' exposure to a temperature of 1500° to 1600° C. in a furnace.

W. J. Rees, *Changes which take place in Silica Bricks during their Use in the Open-Hearth Furnace* (Journal of American Ceramic Society, Jan. 1925, vol. 8, pp. 40-42). The results of an examination of a silica brick in use in an acid open-hearth furnace are reported. Four zones of varying characteristics are noted. (1) The end of the brick which has been exposed to the furnace; the material has been more or less completely fused, and it is by the flow of this layer that corrosion mainly takes place. It consists chiefly of cristobolite and magnetite. (2) A black zone graduating into brown on its cooler end; it consists mainly of crystals of tridymite in a matrix of magnetite. The contraction of the first zone has caused the expulsion of the ferruginous slag into the second. The silicates and alumina silicates of lime and alkalis, which have a lower viscosity, are carried in advance of this slag into zone (3), where a concentration of lime and alumina is found. Zone (4) is unchanged brick. Under normal circumstances it does not become hot enough for changes to occur.

H. C. Harrison, *Roof Bricks for the Open-Hearth* (Journal of American Ceramic Society, Sept. 1924, vol. 7, pp. 698-705; U.S. Bureau of Mines, 1924). The conditions which a roof brick of an open-hearth furnace has to withstand are considered, and some suggestions are made as to the possibility of improving refractories in common use.

F. A. Harvey and E. N. McGee, *Factors affecting Resistance of Silica Refractories to Abrasion* (Journal of American Ceramic Society, Dec. 1924, vol. 7, pp. 895-906). A simple apparatus was employed to measure the resistance to abrasion, the apparatus consisting mainly of a direct driven crystolon wheel which produces a surface groove in the test-piece. It was attempted to correlate the factor of resistance to abrasion with other properties, such as porosity, apparent specific gravity, residual expansion, and degree of firing. In general the resistance to abrasion decreased with increasing porosity, but this relationship is not absolute. It varied directly and consistently with the degree of firing. The effect of refiring silica bricks was to increase their resistance to abrasion by 20 to 30 per cent., probably owing to the formation of a hard skin and a stronger bond.

S. Cornell, *Some Considerations Necessary in Selection of Refractories for the Open-Hearth* (Journal of American Ceramic Society, Sept. 1924, vol. 7, pp. 670-681). The quality and quantity of refractory brick used in steel furnaces, coke-ovens, and blast-furnaces are discussed, and the factors that influence the life of bricks in the open-hearth furnace are considered.

C. E. Williams, *Operating Conditions in the Open-Hearth as they Affect Refractories* (Journal of American Ceramic Society, Sept. 1924, vol. 7, pp. 681-686 : U.S. Bureau of Mines, 1924).

Some Considerations Necessary in Selection of Refractories for the Open-Hearth (Journal of American Ceramic Society, Sept. 1924, vol. 7, pp. 705-716). A general discussion on open-hearth refractories conducted by D. A. Lyon.

F. H. Norton, *General Theory of Spalling* (Journal of American Ceramic Society, Jan. 1925, vol. 8, pp. 29-39). Spalling is defined as the fracture or disintegration of a material caused by rapid changes in temperature. The results of measurements of the properties of refractory bricks indicate that a good spall-resisting brick should have a high diffusivity, a low coefficient of expansion, and a high flexibility in shear.

A. I. Andrews, G. A. Bole, and J. R. Withrow, *The Making of Dolomite Brick and a Study of their Properties* (U.S. Bureau of Mines : Journal of American Ceramic Society, Feb., Mar. 1925, vol. 8, pp. 84-100, 171-190). This report to the U.S. Bureau of Mines contains the results of an investigation upon the making and properties of dolomite brick. A review of the literature has shown that many improvements are possible, and some of the principal sources of error are pointed out.

M. C. Booze, *Fireclay Brick for the Open-Hearth* (Journal of American Ceramic Society, Sept. 1924, vol. 7, pp. 686-690). The use of fireclay brick for open-hearth furnaces is confined almost entirely to the regenerators, where the temperature is not generally in excess of 2600° F. The temperature, however, may approach that of the furnace chamber if for some reason the valves are not reversed at the regular period.

R. E. Griffith, *Chrome Refractories for the Open-Hearth* (Journal of American Ceramic Society, Sept. 1924, vol. 7, pp. 690-698). The pro-

perties of chrome bricks are discussed. In the crushing test the point of failure under the standard load test is generally between 1430° and 1470° C. for bricks containing 50 per cent. of chromite, and such bricks stand temperature changes much better than magnesia and silica brick.

F. A. Kohlmeyer, *Selection of Fire-Brick by Comparative Tests, with a Detailed Description of the Method used to Measure the Temporary Expansion or Contraction of Fire-Brick at Various Temperatures* (Journal of American Ceramic Society, May 1925, vol. 8, pp. 313-318).

P. Gilard, *Scorification Tests of Refractory Materials* (Revue Universelle des Mines, Dec. 1, 1924, vol. 4, Series 7, pp. 281-284). A comparative discussion of the values of the U.S. Bureau of Standards test, in which refractory bricks are heated for thirty-six hours at 1400° C. in contact with certain slags, the Carnegie Steel Company's method, in which the slag is packed into a cavity in the brick and heated at 1350° C. for five hours, and the Mellon Institute test, in which both slag and refractory are intimately mixed and the softening point of the resulting cones determined. To these three forms of test are now added two more. In one of these, the Rose test, a cylinder of the refractory material is rotated in a bath of the molten slag, and subsequently removed for examination as to depth of penetration, identical conditions being, of course, imposed during each test. In the Norton test, on the other hand, the molten slag is made to trickle along a channel grooved in the refractory test-piece. These two new methods yield information as to chemical action, abrasive resistance, penetration, &c., not furnished in a form so complete in the earlier tests. The results resemble closely those likely to be attained in actual practice, and are, from this point of view, probably of greater value than those of the older tests.

R. F. Geller, *Laboratory Testing of Aluminous Refractories* (Journal of American Ceramic Society, Sept. 1924, vol. 7, pp. 663-669). Eight kinds of aluminous refractories, containing 50 per cent. alumina or over, and two kinds of fireclay refractories, such as are used for lining rotary cement kilns, were tested for refractoriness, contraction, resistance to effects of quenching, to deformation under load, and to slag attack. The softening point of the highly aluminous refractories was at about that of the Orton pyrometric cone 34; the change in linear dimensions after heating at 1400° was very small. The samples withstood 18 or more quenchings. The deformation at a maximum temperature of 1450° C. did not exceed 5 per cent. under a load of 25 lbs. per square inch.

M. C. Booze, *Effect of Red Hearts in Fireclay Brick* (Journal of American Ceramic Society, Apr. 1925, vol. 8, pp. 227-231). Tests were made on two brands of fireclay brick, which indicate that red hearts, usually considered as being detrimental, add to both the hot and cold strength, and would only be objectionable in furnaces operated at a low temperature. The results of tests are given, together with porosity and iron oxide determinations.

A. V. Henry, *The Electrical Resistivity of Refractories* (Journal of American Ceramic Society, Oct. 1924, vol. 7, pp. 764-782). The electrical

resistivities of flint fireclay, kaolin, magnesite, sillimanite, silica, and diaspore were determined up to a temperature of 1500° C. The tests were made in an atmosphere of nitrogen by the Wheatstone bridge method. Of the materials tested magnesite has the highest resistivity at low temperatures, while at high temperatures it falls almost to that of flint fireclay, which has the lowest resistivity at all temperatures. Curves are plotted for all the materials examined.

E. Steinhoff and F. Hartmann, *A New Process for Testing Refractory Materials by Means of Colour Etching* (Stahl und Eisen, Mar. 5, 1925, vol. 45, pp. 337-343). The authors describe a new process for examining the structure of refractory materials by means of colour etching. After thorough cleaning of the surface of the specimen, it is boiled in a mixture consisting of equal parts of concentrated hydrochloric acid and saturated aluminium chloride solution. After cooling it is carefully washed in water and then exposed for half an hour to the action of a concentrated methylene blue solution. The specimen is again washed, and a tinting effect becomes clearly visible, which fades after a certain time. This is a rapid tinting macroscopic method for quickly ascertaining the quantity and distribution of certain constituents. For permanent macroscopic tinting, the specimen, which may have clean fractured surfaces or be roughly ground or fine polished, is subjected to the acid attack for twenty-four hours at 50° to 60° C., then washed in water for a few minutes, and immersed for several hours in a concentrated solution of methylene blue. The excess colouring matter is removed from the pores by washing for about an hour, and the tints then show up plainly. The shades of the tints vary according to the firing temperature of the bricks, and the different constituents and impurities show up in different colours. The method also reveals the extent of the quartz transformation in silica bricks.

A. T. Green, *The Influence of Texture on the Transmission of Heat through Firebricks* (Transactions of the Ceramic Society, 1923-24, vol. 23, pp. 253-270). The effect of porosity and permeability to gases is discussed. It is considered that the transmission of heat by way of the pore spaces, by the phenomena of convection and radiation, takes place in quantities comparable with that by way of conduction through the solid matter at the higher temperatures of experiment (1270° to 870° C.). Transmission by means of convection takes place to a much greater extent in the more permeable bricks, that is, the bricks of higher grog content. The thermal conductivity of well-fired silica bricks is greater at high temperatures than that of firebricks.

A. T. Green, *The Thermal Conductivity and some other Properties of two Commercial Heat-Insulating Bricks used in Kiln Construction* (Transactions of the Ceramic Society, 1923-24, vol. 23, pp. 271-276).

P. Gilard, *On the Thermal Conductivity of Refractory Materials* (Revue Universelle des Mines, Oct. 1, 1924, vol. 4, Series 7, pp. 34-50). Despite many researches, the complexity of the factors involved leaves the subject of the heat conductivity of various refractories in a very

unsettled condition. Conductivity, convection, and radiation are concerned. Molecular heat transmission is affected by chemical composition, the physical structure of the material, its porosity, and its previous treatment; hence the temperature and period of baking often affect the result considerably. The pore spaces, being filled with air, in itself a bad conductor, act more as causing delay than in stopping the heat transmission altogether, and in some circumstances their effect can be annulled, as the walls become the media of actual transmission. The most practical, as compared with merely classical, methods of determining conductivity are enumerated and briefly compared, and the work of various investigators is discussed. Tables are given showing average conductivity in gramme-calories and in kilogramme-calories of various bricks baked at temperatures ranging from 500°C . to 1300°C . These include results obtained with ordinary "refractory bricks" of a nature not otherwise specified: bauxite, silica, and magnesia bricks; chromite bricks; infusorial earth bricks, graphite, and carborundum. A bibliography of the subject accompanies the article.

M. L. Hartmann and O. B. Westmont, *The Thermal Conductivity of Carborundum Refractories* (Journal of American Ceramic Society, May 1925, vol. 8, pp. 259-286). The relation of the thermal conductivity to temperature, chemical composition, and porosity was investigated, as well as the magnitude of the surface and joint effects. The conductivity of carborundum was found to vary with the quantity of heat energy transmitted through the wall. The conductivity measurements were made up to a temperature of 1350°C .

High-Temperature Insulation (Iron Trade Review, Jan. 8, 1925, vol. 76, pp. 151-153). The factors to be considered in the reduction of heat losses from furnace walls are discussed. Firebrick with a minimum conductivity of 6.7 B.Th.U. per square foot per hour at 400°F . increases in conductivity to 13.3 B.Th.U. at 2400°F . Insulating brick averages about twelve times as effective in retarding the passage of heat as the refractory. The low conductivity of this insulating material is due to the fact that it contains a volume of as much as 85 per cent. of infinitesimal air cells which effectively break up the air waves. Being practically pure silica, the material has a high melting point, 2930°F . It is recommended strictly as an insulating material, however, and in no case should the refractory linings be eliminated, principally due to the fact that the insulating material is not physically constituted to withstand a great deal of abrasion. On the other hand, the crushing strength is unusually high, averaging over 400 lbs. per square inch. In most cases the substitution of a $4\frac{1}{4}$ -inch course of insulating brick for a course of common brick in furnace walls will cut down the heat loss from 65 to 70 per cent. A table is given showing the effect of insulating various thicknesses of walls at different temperatures.

O. Rebuffat, *Synthesis and Industrial Manufacture of Sillimanite* (Transactions of the Ceramic Society, 1923-24, vol. 23, pp. 312-313). It is not possible to make sillimanite by the reaction at high tempera-

tures of dry mixtures of hydrated silica and alumina and then firing the mixture to 1400° C. But if hydrated alumina be very intimately mixed by the wet method with kaolinite and then gradually heated to 1400° C., sillimanite is definitely formed. The product not only has the percentage composition of sillimanite, but possesses the main characteristic properties of the mineral, namely, its indifference to hydrofluoric acid, its high refractoriness, and its stability of volume.

H. Wilson, C. E. Sims, and F. W. Schroeder, *Artificial Sillimanite as a Refractory* (Journal of American Ceramic Society, Nov., Dec., 1924, vol. 7, pp. 842-845, 907-919). Comparative tests were made on sillimanite and other types of refractories as to their resistance to thermal shock, both the water-quenching and air-cooling methods being used in making the spalling test. Under both methods the stony type of sillimanite proved superior to the glassy type, and gave better results than zirconia, silica, or magnesia bricks. Laboratory tests show that sillimanite-corundum bricks withstand higher temperatures than silica, magnesia, chrome, fireclay, or zirconia bricks. They resist acid slags, and the structure is sufficiently dense to give a greater resistance to basic slag than the more porous silica bricks. Lime above 1.5 per cent. in a sillimanite brick will seriously reduce the fusion temperature.

R. F. Geller, *Testing of Fireclay Brick, with Special Reference to their Use in Coal-Fired Boiler Settings* (United States Bureau of Standards, 1925, Technologic Paper No. 279).

V. C. Faulkner, *Some Notes on Refractory Materials* (Paper read before the London Section of the Institute of Metals: Foundry Trade Journal, Feb. 19, 1925, vol. 31, pp. 153-154). The characteristics of refractory materials used in the metal industry are discussed.

J. T. Mackenzie, *Practice Limits Refractory Life* (Foundry, Apr. 1, 1925, vol. 53, pp. 267-271). The author discusses the effect of variations in practice on the life of cupola linings.

FUEL.

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I.—CALORIFIC VALUE.

Pyrometry.—R. W. Newcomb, *Classification and Application of Pyrometers* (Proceedings of Engineers' Society of Western Pennsylvania, Oct. 1924, vol. 40, pp. 249–267). The four types of pyrometers in most general use are the thermo-electric, the electric resistance thermometer, the optical pyrometer, and the radiation pyrometer. For temperatures below 800° C., the electric resistance thermometer is the most useful, as it can be depended on to register accurately from absolute zero. The thermo-electric system is suited for temperature ranges up to 1500° C., and optical and radiation pyrometers have their principal field of usefulness at any higher range than 1500° C. The metals used for thermocouples should be of the highest purity obtainable. A base metal thermocouple of the iron-constantan type gives best service under reducing conditions. The chromel-alumel thermocouples are best suited for oxidising conditions, but are unsatisfactory where conditions are alternately reducing and oxidising. No fixed rules can be applied in any one case, and it requires experiment to find the right combination of thermocouple and protecting tube for a given set of conditions.

C. B. Thwing, *The Use of Radiation Pyrometers on Refractory Kilns* (Journal of American Ceramic Society, Feb. 1925, vol. 8, pp. 115–116). Owing to the high cost of maintenance of platinum thermocouples the use of pyrometers of this type for kilns firing silica and other high refractories has been discouraged. The author describes a method of using a combination recorder employing thermocouples for the lower ranges of temperatures and the radiation pyrometer for the higher ranges. The accuracy of measurement is fully equal to that made with platinum thermocouples at the temperatures for which the latter are durable, and the radiation pyrometer has the further advantage that it has no upper limit of temperature. The higher the temperature the more efficiently the pyrometer works.

H. A. Schwartz, *Pyrometers* (Transactions of the American Society

for Steel Treating, Apr. 1925, vol. 7, pp. 518-528). The author outlines briefly the developments of the art of pyrometry and discusses the various methods of determining temperatures. He describes the radiation, thermocouple, and optical types of pyrometers.

A. Fry, *Optical Temperature Measurements in Practice* (Stahl und Eisen, Nov. 6, 1924, vol. 44, pp. 1398-1405). A summary is given of the points necessary to observe in taking temperature measurements with an optical pyrometer. A useful set of curves is given showing at a glance the corrections requiring to be made to the readings of an optical pyrometer in judging the temperature of a bath of iron, carbon steel, and alloy steels, with and without a slag covering.

H. Schmidt, *The Principles of Colour Pyrometry* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1924, vol. 6, pp. 7-15). The author discusses the two general principles on which optical pyrometry is based, the one in which the temperature is judged by the intensity of the heat radiation, the other in which it is judged by the colour which a heat-radiating body presents to the eye. Attention is directed to the difference between the temperature of a monochromatic radiation and that of rays emitted by a hot body.

C. Roszak and M. Véron, *Calorific Radiation from the Point of View of its Industrial Applications* (Revue de Métallurgie, Aug., Sept., Oct., 1924, vol. 21, pp. 435-449; 549-564; 600-609). A closely reasoned discussion of the laws of radiant heat, and of the principles of its application in metallurgical and other furnaces. The subject is discussed under the following heads: Definitions; the behaviour and laws of black bodies; the interactions of radiation and its calculation, including the differential analysis of angular terms and derived formulæ; and the practical application of such laws and formulæ in concrete cases of polished and roughened surfaces, and the relations between radiation and convection, in furnace design.

Combustion of Fuel.—F. S. Sinnatt, *Selective Combustion in Coal* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). Coal has been found to propagate a zone of combustion provided the particles are smaller than a critical size. The rate of propagation of the zone and the temperature attained depend on the type of coal, the size of the particles of coal, and the availability of the oxygen required for combustion. Temperatures as low as 130° C. during continued propagation of the zone have been recorded. Inert materials, such as rock dust and calcium carbonate, when mixed with coal dust do not inhibit the combustion unless the amount present exceeds 50 per cent. for shale dust and 70 per cent. for calcium carbonate. The oxidation product formed by allowing a zone of combustion to permeate powdered coal in a limited supply of air contains a relatively high percentage of oxygen compared with that present in the original coal. It would appear that if a particular coal can be ground to form a powder, the particles of which are smaller than a limiting size, spontaneous

combustion may take place; conditions in the mine that bring about the grinding of coal are consequently contributory factors toward gob fires. Pyrite appears of secondary importance. Thus seams may contain an extremely active form of pyrite and spontaneous combustion may be quite unknown; other seams in which the type of pyrite is inactive are liable to fire in the goaf.

F. S. Sinnatt and L. Slater, *Propagation of a Zone of Combustion in Powdered Coal; Minimum Temperature for Combustion* (Fuel, 1924, vol. 3, pp. 350-355). It is found that finely powdered coal will oxidise in a restricted supply of air, and the rise in temperature will depend on the rate of access of the air. The lowest temperature at which oxidation can proceed through the mass was found to be 130° C. and when this temperature is reached, the coal may oxidise rapidly along a very irregular path, breaking out into active ignition if the supply of oxygen is sufficient.

R. V. Wheeler, *Ignition of Coal* (Fuel, 1924, vol. 3, pp. 366-370). Forty different coals were tested and their relative ignition temperatures were determined by the point of intersection of heating curves of the coal contained in a glass tube through which air is passed and of the curves of the sand bath in which the tube is embedded. The coals which most readily heated were those containing the highest proportion of oxygen.

D. Aufhäuser, *Carbon and Coke* (Glückauf, Dec. 20, 1924, vol. 60, pp. 1195-1201). The article deals mainly with the nature and properties of carbon and its compounds and the theory of combustion.

W. A. Bone, *Gaseous Combustion at High Pressures* (Proceedings of the Royal Institution of Great Britain, Apr. 1925, vol. 24, pp. 131-157).

J. B. C. Kershaw, *The Combustion of Pulverised, Liquid, and Gaseous Fuels* (World Power, Feb. 1925, vol. 3, pp. 78-85).

C. V. Boys, *Measurement of the Heating Value of Gas* (Proceedings of the Royal Institution of Great Britain, Apr. 1925, vol. 24, part 1, pp. 109-114).

Industrial Heating.—C. de la Condamine, *The Calculation of the Calories carried away by the Escaping Gases and Lost in the Clinkers* (Chaleur et Industrie, Aug. 1924, pp. 418-424). A highly detailed investigation, with formulæ and tables, of the mode of investigating such losses in various furnaces, boilers, and other industrial contrivances.

E. F. Collins, *Intrinsic Value of Heat Sources versus the Fluctuating Economic Value of the B.Th.U.* (Transactions of the American Society for Steel Treating, Jan. 1925, vol. 7, pp. 82-100). The paper aims at showing that there is little of value in knowing the relative British thermal unit costs for a heat source unless all conditions surrounding the use of the heat source are also known. It is impossible to select that heat source giving the greatest "over-all" economy unless all conditions of its utilisation enter in at their true intrinsic value for the specific process in hand. Greater co-operation is needed between the

metallurgist, furnace operator, and engineer. Some examples are given showing by areas of triangles, which represent heat energy value, how the intrinsic value of the B.Th.U. fluctuates from one value to another, due to different conditions of utilisation, &c., and the conclusion is drawn that: The highest over-all economy in heat-treating processes frequently demands electric heat with its intrinsic characteristics, such as "form value," heat and temperature control, rather than fuel heat with its lower B.Th.U. cost.

R. J. Sarjant, *Furnace Heating* (Fuel, Jan. 1925, vol. 4, pp. 5-14). The relative suitability of solid, liquid, and gaseous fuels for the heating of furnaces is discussed, and the conditions for efficient combustion are expounded.

J. A. Hunter, *The Generation and Utilisation of Steam in the Iron and Steel Industry* (Mechanical Engineering, June 1924, vol. 46, pp. 325-328). Recent progress in the design of plant for generating and using steam is reviewed, and data are given as to the quantities and cost of fuel and the cost of converting the heat in the fuel into steam. The probable saving which could be effected, if all the steam required in the industry could be made and consumed in the most efficient apparatus now available is estimated at over 97 million dollars.

Pulverised Coal.—H. G. Barnhurst, *The Preparation of Pulverised Coal* (Mechanical Engineering, Feb. 1925, vol. 47, pp. 87-88). The operations of crushing, drying, and pulverising coal and the kind of plant required for these are briefly described.

F. L. Wolf and W. Romanoff, *Powdered Coal in a Malleable Casting Plant* (Paper read before the American Foundrymen's Association, Oct. 1924).

S. Westberg, *Pulverised Fired Malleable Furnaces* (Blast-Furnace and Steel Plant, Jan. 1925, vol. 13, pp. 46-47). Many furnaces melting iron for malleable castings are now using pulverised coal as fuel, and such furnaces are being designed on the recuperative principle. Carborundum has been found to be a very suitable material for the construction of recuperators, and an illustration shows a newly designed melting unit, consisting of two malleable melting furnaces with a single set of carborundum recuperators between. The melting power of the furnace is much increased due to the higher temperatures attainable with pulverised coal and preheated air. The shortened time of melting and the less excess of air or free oxygen results in lower oxidation losses.

H. W. Brooks, *The Development of Pulverised Coal as a Boiler Fuel* (Mechanical Engineering, Feb. 1925, vol. 47, pp. 89-93). The author gives a short historical review of the development of the use of pulverised coal as fuel, showing that the main principle of introducing fuel and air together was conceived nearly a century ago. The first patent relating to pulverised coal was a British patent granted in 1831 to John Samuel Dawes, ironmaster, of Bromford, in the county of Stafford. Subsequently T. B. Crampton in 1868 carried out a long series of experiments

in the use of pulverised coal for firing puddling furnaces and boilers. (See this Journal, 1873, p. 91.)

F. Schulte, *Present Development of Boiler-firing with Pulverised Coal* (Zeitschrift des Vereines Deutscher Ingenieure, Sept. 27, Oct. 11, 1924, vol. 68, pp. 1021-1025, 1071-1074). The author describes recent developments in the practice of firing boilers with powdered coal in Germany, giving results of trials and efficiencies.

Pulverised Fuel at the Trumbull Steelworks (Iron and Coal Trades Review, Apr. 24, 1925, vol. 110, pp. 657-658). The application of pulverised fuel to the firing of boilers and annealing furnaces is described.

E. Kilburn Scott, *Pulverised Fuel for Large Power Stations* (Transactions of the Society of Engineers, 1924, pp. 129-162). Various types of pulverisers and the Lopulco system of firing pulverised fuel are described and illustrated.

I. G. Coutant, *Pneumatic Conveying of Pulverised Coal. Blow Tank Method* (Power, Aug. 5, 1924, vol. 60, pp. 215-216). The article describes an installation consisting of a 5-ton blow tank and air-compressor at the Dilworth Porter Company's works, Pittsburgh. With a 4-inch transport main the air and coal passed at the rate of 2000 lb. per minute, the temperature of the pipe rising to about 100° F. The initial air pressure was 50 lb. per square inch and about 1.37 lb. of coal were transported per cubic foot of air.

II.—COAL.

Africa.—A. E. Gerard, *The Coal Wealth of the Zambesi* (Mémoires de la Société des Ingénieurs Civils de France, Bulletin, Apr.-June 1924, pp. 244-261). After a short account of the general coal resources of Africa, the deposits of the Zambesi region are specially described. Three main coalfields are recognised: N'Goma Sinjal, Nyakale, and M'Situ. The coal in these regions is scanty and not of good quality. In the Tete region, however, excellent deposits occur; a rough estimate based on two-thirds of the area explored places the resources at 105 millions of tons, at easy depths. Some of the seams are 10½ yards thick. The coal cokes well, is not high in ash, and contains not more than 1 per cent. of sulphur. The deposits are not too far from Beira to be transportable economically.

Australia.—*The Power Resources of the Commonwealth of Australia and the Mandated Territory of New Guinea* (Report to the World Power Conference, London, 1924. Compiled by the Institution of Engineers, Australia. Sydney, 1924). Detailed information derived from various sources is given concerning the water power, coal, and liquid fuel re-

sources of the Commonwealth. The principal coal deposits are situated along the eastern and south-eastern portions of the continent, in Tasmania, and in the south-western corner of Western Australia. The productive coalfields of New South Wales occur in Permo-Carboniferous rocks, in the form of a great basin, of which the City of Sydney is approximately the centre, and extend along nearly 150 miles of the eastern coast from the neighbourhood of Port Stephens on the north to the Shoalhaven Valley on the south. In addition, several small areas of coal of Greta Age in the neighbourhood of Jervis Bay and Clyde River occur south of the Shoalhaven River. The deepest part of the basin is in the neighbourhood of Sydney, where the Sydney Harbour Colliery worked the uppermost seam at a depth of 2784 feet below sea level. Hence the coal measures rise gradually but irregularly towards the north, south, and west. Thus the coal seams outcrop in the neighbourhood of Newcastle, Bulli, and Lithgow, at heights above sea level of 200, 400, and 3000 feet respectively. The principal seams from which good coking coal is at present being obtained are : The Borehole seam in the Northern Coalfield, the Bulli seam in the Southern Field, and in restricted areas of the Lithgow seam in the Western Field. The method of coke production in New South Wales has not kept pace with modern practice. With the exception of the plant of the Broken Hill Proprietary Co. at Newcastle, where a modern by-product plant is in operation, the types of oven in general use are the true beehive and the rectangular beehive, the latter type predominating.

So far black coal has only been found in Victoria associated with rocks of Jurassic Age, and these beds are situated to the south of the Dividing Range, and extend southward beneath Bass Strait. South Gippsland is the most important area, and a large amount of prospecting work has been done in the district. Brown coal of Tertiary Age occurs in numerous areas throughout the State ; the largest is in Gippsland, in the valley of the Latrobe River, with Morwell as a centre. Boring has proved seams upwards of 700 feet in thickness. The quality of the brown coal varies ; in part it is chiefly lignite, while closely adjacent no woody matter is present. The moisture content is also variable ; the oldest or sub-older basaltic brown coals are lowest in moisture. The ash content is remarkably low, especially in the thick seams.

Queensland has vast regions of coal-bearing lands, the deposits occurring in many portions of the central and southern districts and in a few localities in the northern and western districts. Of the coal-bearing formations the Cretaceous deposits are of minor importance, the Trias-Jura measures being those from which most of the coal supplies are now obtained. In future, the inland Permo-Carboniferous formations will be an important source of supply, but most of these deposits remain untouched at the present time. The coal reserves of the different districts throughout the State are tabulated.

Coals of different geological ages are known in Western Australia, but have only been extensively mined in one district, the Collie field:

Lignites and brown coal also occur, but these are mostly of poor quality.

In Tasmania coal seams occur in strata belonging to the Permo-Carboniferous, Trias-Jura, and Tertiary systems. The Trias-Jura coal measures are extensively developed in the eastern, midland, and south-eastern portion of Tasmania. These seams constitute the most important coal resources of Tasmania, and vary in thickness from 3 feet to 16 feet, the most important having an average thickness of 12 feet.

The occurrences of coal in New Guinea are small and of no commercial importance. For the most part it is lignitic in character.

Numerous analyses of the different coals of the various States are included in the report.

L. F. Harper, *The Coal Resources of the Douglas Park Area* (New South Wales Geological Survey, 1924, Mineral Resources, No. 32). The occurrence of coal in the Douglas Park area of New South Wales is described. The report includes map, diagram, tabulated list of coal bores in the counties of Cumberland and Camden, and a list of references to the literature on the subject.

Canada.—J. McEvoy, *Smoky River Coal Field* (Canada, Dominion Fuel Board, Report No. 7, Ottawa, 1925). The report deals mainly with the coal deposits in the neighbourhood of Smoky River and Peace River, included in the National Coal Reserve in Alberta, but it also refers to the deposits in the area lying between the reserve and the Canadian National Railway at Brûlé Lake. A part of the report is devoted, by way of comparison, to a discussion of coals from the same formation (Kootenay), in the southern part of the province.

J. MacVicar, *Preliminary Investigation of Coal Deposits on Smoky, Hay, and Berland Rivers, Alberta* (Canada Geological Survey, 1923, Summary Report, Part B., pp. 21–62). An account is given of the general, structural, and economic geology of this district.

D. B. Dowling, *Bow River Coal Basin within the Rocky Mountains, Alberta* (Canada Geological Survey, 1923, Summary Report, Part B, pp. 63–85). The author describes the general structure of the coal areas of the Bow River Valley.

J. A. Allan, *Geology of Alberta Coal* (Bulletin of the Canadian Institute of Mining and Metallurgy, Apr. 1925, pp. 387–405). The author presents some new facts obtained as a result of recent study of the occurrence and character of Alberta coal.

E. Stansfield, *A Chemical Survey of Alberta Coals* (Bulletin of the Canadian Institute of Mining and Metallurgy, Apr. 1925, pp. 406–420). The paper gives a good deal of information regarding the proximate analyses and calorific values of samples of Alberta coals.

J. H. H. Nicolls, *Survey of Maritime Province Coal* (Canada, Department of Mines, Mines Branch, Investigations of Fuels and Fuel Testing, 1923, Ottawa, 1924, pp. 11–27). The results are given of an examination of a number of samples collected from the principal coalfields of

New Brunswick and Nova Scotia. Analyses of the different coals are tabulated.

China.—G. D. Hubbard, *Coal in China* (Economic Geology, 1924, vol. 19, p. 641). The author presents a preliminary report on some coals from Szechuan, China. In this region, known as the Red Basin, are ten more or less parallel anticlinal folds, each of which has coal, continuous along the folds. The seams are 3 to 6 feet in thickness. Of seventeen coals tested two were cannel coal, three sub-anthracite, and twelve bituminous. The heating value of five samples varied between 12,707 and 19,072 B.Th.U., and the percentage of ash from 7.56 to 35.33.

England and Wales.—*Physical and Chemical Survey of the National Coal Resources* (Report of the Fuel Research Board: Iron and Coal Trades Review, Oct. 24, 1924, vol. 109, pp. 661–662). The third report of a series describing the coal-seams of Great Britain from a chemical and physical standpoint. The present report describes the Arley Seam in the Lancashire coalfield.

J. H. Davies, *The Correlation of Coal-Seams in South Wales* (Paper read before the Manchester Geological and Mining Society: Colliery Guardian, Jan. 23, 1925, vol. 129, pp. 211–214).

France.—R. Esparseil, *The Lignites of the Minervois Field (France)* (Revue de l'Industrie Minérale, Mémoires, Feb. 15, 1925, pp. 72–88). The lignite deposits occur in a district situated in the Departments of Aude and Hérault, some 30 kilometres north-east of Carcassonne. The geological formation is Eocene and the mines date back to 1776. Some 3,500,000 tons of lignite are estimated to occur in the nine concessions existing, but this estimate is probably far too low. The deposits were worked during the war, when every description of fuel was eagerly sought after, but have not since been exploited. It is now proposed to utilise these lignites for distilling. The semi-coke which is left over will be used in coke gas-producers. Analyses of the lignite and of the products of its distillation are given. The ovens are of mixed types, the Pieters, the Salerni, and the Laurent being installed. Each type is described and illustrated.

C. Barrois, P. Bertrand, and P. Pruvosi, *A New Palæontological Map of the Nord Basin* (Revue de l'Industrie Minérale, Mémoires, July 15, 1924, pp. 353–360). A palæontological and stratigraphical correlation of the most recent researches bearing upon the geology of the coal area in the Nord Department of France, and its prolongation to the Pas-de-Calais coalfield, compiled with a view to filling the gaps which have hitherto existed in regard to such surveys of the region.

Economics of French Coal Industry.—Georges, *The Increase in Production during 1923 at Collieries in the Pas-de-Calais and in the Nord*

(Revue de l'Industrie Minérale, Mémoires, Aug. 1, 1924, pp. 391-394). The daily output of collieries in these two Departments is given as follows :

	Tons.
Nord (97 per cent. of 1913 production)	22,000
Pas-de-Calais (enemy-occupied collieries, 66 per cent. of 1913 production)	26,000
Pas-de-Calais (non-occupied collieries, 113 per cent. of 1913 production)	33,000
Daily total	81,000

This is about equivalent to 90 per cent. of the pre-war production, and at two of the largest collieries reconstruction is not completed. To supply the labour requirements, 55,600 foreigners (of whom 43,000 were Poles) had been introduced into the regions up to the end of the year 1923, and 8700 dwellings for their accommodation have been built. The underground workers are now 50 per cent. French and 50 per cent. foreigners, and the results have been perfectly satisfactory. The proportion of foreign labour at some collieries is far in excess of the average. Thus, at Ostricourt and at Drocourt no less than 70 per cent. of foreign labour is employed. In the Pas-de-Calais alone 5967 percussive drills have been installed as compared with 1392 in use in 1913. It is estimated that within about ten years the coal production in these two coalfields should reach 40 to 45 million tons per annum.

Saar District.—Saint-Claire-Deville, *The Organisation of the French Domanial Collieries in the Sarre* (Revue de l'Industrie Minérale, Mémoires, Feb. 15, 1925, pp. 63-71). A brief account of the former Prussian organisation which directed and administered the collieries of this region, and of the newer organisations which the French have substituted for it. The pre-war output from the collieries grouped in this organisation was 13 to 14 million tons of coal annually, an output which has since been increased and is still increasing. Details are given of the methods by which the various sections charged with finance, sales, administration, technical exploitation, power supply, labour supervision, welfare, safety, and coal handling, washing, and transport are linked together. Liaison is both vertical and horizontal, and regular conferences take place at stated intervals between the heads of all the departments, for mutual consideration of the whole scheme of working.

Vouters, *Three Years of Applied Analysis and Synthesis to the Underground Working in the Sarre and Moselle* (Revue de l'Industrie Minérale, Aug. 1, 1924, pp. 395-401). An analytical description of the improved methods of working adopted since the war in collieries in the Saar district and Moselle is given.

Hungary.—J. Herczegh, *The Collieries of the First Danube Steam Navigation Co., near Pécs, Hungary* (Paper read before the Midland

Institute of Mining Engineers, Oct. 22, 1924 ; Colliery Guardian, Oct. 31, 1924, vol. 128, pp. 1129-1131). The paper includes particulars of the Pécs coalfield, Hungary, together with a description of the mining practice.

United States.—A. J. Collier, *The Scobey Lignite Field, Valley, Daniels and Sheridan Counties, Montana* (United States Geological Survey, 1924, Bulletin 751-E.). The geology of the area and the physical and chemical characteristics of the lignite are described.

C. M. Bauer, *The Ekalaka Lignite Field, South-Eastern Montana* (United States Geological Survey, 1924, Bulletin 751-F., pp. 231-267). The author presents the results of a geological examination of this area. The physiography of the area and the stratigraphy and structure of the sedimentary rocks are briefly described, and the mineral resources are discussed.

Constitution and Chemistry of Coal.—A. C. Fieldner and J. D. Davis, *Modern Views of the Chemistry of Coals of Different Ranks as Conglomerates* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). Modern views of the chemistry of coal take cognisance of the conglomerate and colloidal nature of coal. Microscopical examination has shown the presence of more or less altered plant remains in coal of all ranks. The difference in structure of the "bright" and "dull" bands of bituminous coal has been definitely shown. The bright coal is principally anthraxylon, the dull coal is largely attritus, often containing small strips of anthraxylon ; these are structural differences. The best-known chemical method of resolving coal into groups of compounds is by extraction with pyridine, followed by a subsequent extraction of the pyridine soluble portion with chloroform. The question whether the coal humins come from cellulose or lignin is not settled. The earlier theory that cellulose was the principal contributing factor seems untenable. Recent chemical research tends to favour the theory that lignin is the principal source.

M. C. Stopes and R. V. Wheeler, *The Constitution of Coal* (Fuel, July, Aug. Sept., Oct., Nov., Dec., vol. 3, pp. 254-261, 288-297, 328-335, 356-360, 393-399, 439-452). The articles form the continuation of the series describing the authors' researches on the constitution of coal. The last of the series contains a full bibliography of literature on the chemistry and constitution of coal.

R. Thiessen, *The Constitution of Coal* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925).

H. D. Greenwood, *Examination of the Banded Constituents of a Derbyshire Coal* (Journal of Society of Chemical Industry, Dec. 26, 1924, vol. 43, pp. 363-365-T.). Coal samples were obtained by picking lumps of coal from truck deliveries, and the banded constituents durain, clarain, vitrain, and fusain were separated and subjected to proximate analyses and distillation tests on a laboratory scale. The porosity and specific gravity of the cokes from these tests have also been determined.

The fusain was characterised by low volatile and high ash content and was entirely devoid of coking properties. The vitrain and clarain gave highly swollen cokes, but the durain showed very little change in form, and even a slight decrease in volume on coking.

F. V. Tideswell and R. V. Wheeler, *Banded Bituminous Coal. Studies in the Composition of Coal* (Journal of Chemical Society, Jan. 1925, vol. 127, pp. 110-112).

W. Francis and R. V. Wheeler, *The Oxidation of Banded Bituminous Coal at Low Temperatures. Studies in the Composition of Coal* (Journal of Chemical Society, Jan. 1925, vol. 127).

F. V. Tideswell and R. V. Wheeler, *On Fusain and its Oxidation. Studies in the Composition of Coal* (Journal of Chemical Society, Jan. 1925, vol. 127, pp. 125-132).

F. V. Tideswell and R. V. Wheeler, *The Constitution of Coal* (Paper read before the American Institute of Mining and Mechanical Engineers, Feb. 1925).

C. A. Seyler, *The Microstructure of Coal* (Fuel, Feb. 1925, vol. 4, pp. 56-66). The preparation of coal specimens for microscopic study is described. Instead of cutting thin sections, the author has adopted the plan of cutting with a hack saw one face of the selected coal in a definite direction with regard to the bedding plane, and this is polished by the ordinary metallographic method on a polishing machine. The etching liquid is made by adding 10 cubic centimetres of strong sulphuric acid to 30 cubic centimetres of a saturated solution of chromic acid. Enough water is then added to dissolve any precipitate. A number of micrographs of coal specimens is shown and their structure and constitution are discussed.

C. A. Seyler, *The Microstructure of Coal* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925).

H. G. Turner, *Microscopical Structure of Anthracite* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). The author describes a method for the microscopical examination of anthracite, and gives a number of photomicrographs which show that anthracite is composed of the same kinds of organisms and materials found in bituminous coal. These organisms and their parts are in the same proportions as they are in bituminous coal, and also in a similar state of preservation, except for the greater abundance of structureless bands produced by intense flattening of wood components.

W. Francis and R. V. Wheeler, *The Resolution of Coal by Oxidation* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). The authors describe experiments in which mild oxidising agents are used for studying the constitution of coal.

J. W. Cobb, *Nitrogenous Constituents of Coal* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925).

J. Jolly and R. V. Wheeler, *Organic Sulphur Compounds in Coal* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925).

J. H. H. Nicolls, *A Study of the Nature of Sulphur in Coal and Coke from the Maritime Provinces* (Canada, Department of Mines, Mines Branch, Investigations of Fuels and Fuel Testing, 1923, Ottawa, 1924, pp. 28-38). The author has studied the various forms of sulphur in coal. Coals from New Brunswick and Nova Scotia were selected for the investigation, as these, as a general rule, contain a higher percentage of sulphur than coals from any other part of the Dominion. The report includes a review of recent literature regarding the nature of sulphur in coal and coke, its determination, and the changes that occur during the coking process.

W. T. Thom, jun., *Moisture as a Component of the Volatile Matter of Coal* (Paper read before the American Institute of Mining and Metallurgical Engineers. Feb. 1925). According to the author, it is essential to the formulation of a scientific and systematic classification of coal on a chemical basis that all moisture forming a normal and essential part of coal, as it is found in nature, be recognised and reported in analyses as a component of the coal and not as an extraneous impurity to be excluded from consideration. The utilisation of the air-dried form of proximate analysis appeals to the author as the best method of discriminating between water accidentally present in the coal sample and moisture to be regarded as a natural constituent of the coal.

Melting Point of Coal Ash.—N. Simpkin and F. S. Sinnatt, *The Melting Point of Coal Ash* (Journal of Society of Chemical Industry, May 1, 1925, vol. 44, pp. 197-200-T.). The influence of certain external agencies on the melting point of coal ash is studied. In the first place, it is found that the use of a reducing atmosphere in making the determinations lowers the melting point. The blending of coals from different seams also has an effect on the melting point, and tables giving results of determinations of the melting point of the ash from coals blended in different proportions are shown.

Occurrence and Composition of Peat.—A. Anrep, *Investigation of Peat Bogs in New Brunswick* (Canada Geological Survey, 1913, Summary Report, Part C. 2, pp. 13-22). A detailed description of the character of the peat bogs in New Brunswick, with analyses of peat from the different bogs examined.

J. A. De Grey, *The Artificial Drying of Peat* (Chaleur et Industrie, Aug. 1924, pp. 400-401). Deals with an investigation conducted by Keppeler, and incidentally reviews the difficulties attendant on the drying of peat, and previous processes having that object. An electrolytic method is described, a current of 50 to 100 volts being passed through an emulsion of peat, which acts as a colloidal solution, and results in water being expelled. The comment is made that so far none of the many methods suggested from time to time for the artificial dehydration of peat appear to have been economically successful.

III.—COKE.

Coke-Oven Plant.—E. C. Evans, *The Narrow Coke-Oven* (Fuel Economy Review, July 1924, vol. 4, No. 1, pp. 12–19). Recent investigations have shown that very considerable advantages may be obtained by decreasing the width of coke-ovens, which usually averages from 19 to 21 inches, down to 12 to 14 inches. Trials made by H. Koppers at Essen and by the chemists of the American Koppers Company at Pittsburg show that in a narrow oven not only is the speed of coking increased with the consequent increase in output per oven, but that the physical character of the coke is more uniform, the combustibility of the coke is increased, and there is an increased yield of by-products. As the result, certain radical alterations in the design of the Koppers oven have been introduced, the modified oven being known as the Becker oven. Tests for determining the progression of coking at different heights show that the entire mass from top to bottom was finished at the same time, the difference in temperature usually not exceeding 100° F. A description is also given of the new coke-oven plant at Tinsley Park Collieries, in which the chambers taper vertically from a mean sole width of 20·8 inches to 18·8 inches at the top. The output has been increased 30 per cent. as compared with that of the old ovens with a mean width of 20·8 inches at top and bottom, and of the same height as the new ones.

O. Peischer, *New Types of Coke-Oven* (Stahl und Eisen, Feb. 12, 1925, vol. 45, pp. 224–231). The author discusses modern developments in coke-oven construction and design and the influence of these on output and quality of the coke. Practical experience with ovens having narrow chambers is described, and calculations show that the actual efficiency of ovens with a width of 350 millimetres (about 14 inches) is 64 per cent. higher than that of ovens 500 millimetres wide (about 19¾ inches). The coking time is reduced by one-half, and the quality of the coke is much more uniform, less heat is required for the conversion of the coal into coke, and the combustibility is improved. Illustrations show the Koppers oven with tapered chambers, the Becker oven, which is the American Koppers new type, and the Still coke-oven.

O. Peischer, *New Coke-Oven Types* (Iron and Coal Trades Review, Feb. 13, 1925, vol. 110, pp. 249–251). The author discusses the developments in the design of coke-ovens. The introduction of narrow chambers has led to increased carbonising capacity of oven, more uniform heating, and reduced heat consumption.

Piette Coke-Ovens (Engineering, Oct. 10, 1924, vol. 118, pp. 510–512). A description of new coke-oven plant at the works of the Shelton Iron, Steel and Coal Company. The new installation consists of a battery of twenty-four ovens of the Piette type constructed of silica brick. Sectional drawings and plans of the oven are given.

More By-Product Coke Plants for Iron Industry (Iron Age, Jan. 8,

1925, vol. 115, pp. 128-130). A table is given showing the individual firms operating by-product coke-ovens in the United States, and the number and capacity of the ovens. At the end of 1924 there were built or building 11,954 by-product ovens, with an annual carbonising capacity of 68,391,366 net tons of coal and an expected yield of 50,838,975 tons of coke. The largest single by-product plant in the United States is that of the Carnegie Steel Co., at Clairton, with 1134 ovens capable of producing 6,350,000 tons of coke annually.

C. Berthelot, *Recent Progress in the Construction and Operation of Coke-Ovens* (Chimie et Industrie, May 1924, pp. 234-252).

C. Berthelot, *Coke-Ovens. Their Modern Construction and Working* (Mémoires de la Société des Ingénieurs Civils de France, Bulletin, July-Sept. 1924, pp. 383-432). Deals with the subject more particularly from the point of view of French practice. Broadly, the conclusions arrived at are that it is possible, with advantage, to reduce the present width of modern ovens, and to increase their height and length, the latter to a considerable extent, and to carry out the coking process with far better results in ovens of the modified dimensions. Water-gas or blast-furnace gas can be used to heat them, the more valuable coke-oven gases being more usefully applied about the works. The Solvay-Piette or Coppée systems of coke quenching are strongly recommended as the most satisfactory.

L. F. Harper, *Coke* (New South Wales Geological Survey, 1924, Bulletin No. 12). The report gives particulars of the development of the coke industry of New South Wales, subsequent to 1916, together with statistics of production and related subjects. There are at present fourteen coke-making plants in operation. Particulars are included of the practice at each individual works.

J. L. Landt, *Coke as a Household Fuel in Central Canada* (Canada Dominion Fuel Board, Report No. 5, Ottawa, 1925). The report discusses the possibilities of the use of by-product coke as a domestic fuel in Central Canada. The report includes detailed descriptions of various types of by-product coke-ovens.

Manufacture of Coke.—E. Trasenster, *Three Days in the Sarre and in Alsace with the Congress of Mineral Industry* (Revue Universelle des Mines, Mémoires, Feb. 1, 1925, vol. 5, pp. 142-155). In a report of visits paid to the French Domanial Collieries in the Saar in June 1924, the author describes the coking practice at the Heinitz Works, and the methods of oil extraction at the Pechelbronn deposits. Saar coal is highly bituminous, having 31 to 34 per cent. of volatile matter. On coking by itself great shrinkage takes place, and although, on drawing, it yields to all appearance a very satisfactory metallurgical coke it is so friable that on transport it breaks into small lumps, accompanied by an economically undesirable proportion of fines. This is due to the large amount of the volatile matter

in the original coal, and therefore the practice has been to mix the coal with leaner coals from other regions, in the proportion of 10 to 25 per cent. of leaner coal, the mixture being intimately mixed and powdered before charging to the ovens. Coking the unpowdered mixture in specially narrow ovens is alternatively practised, both methods yielding excellent hard coke. It is obvious, however, that the dependence upon outside coal supplies would lead to a precarious situation. The problem has been solved by rendering part of the home supply leaner by partial distillation previous to mixing it with the remainder of the untreated native coal. The semi-distillation is conducted in small rotary ovens at a temperature not exceeding 450 to 470° C. Tests have shown that the coke which is obtained by mixing the native coal with the semi-distilled product is so far superior to that obtained by coking the native coal in the ordinary way that a plant has been installed capable of supplying the needs of a battery of thirty ovens. Only 20 per cent. of the mixture being volatile, an excellent yield is obtained. The low-temperature carbonisation of the admixture gives a high yield of valuable gas and by-products.

R. A. Mott, *By-Product Coke-Oven Practice* (Fuel, Jan., Feb. 1925, vol. 4, pp. 15-23, 67-74). A general account is given of the development of by-product coking practice, with illustrations of various types of ovens. Recent changes in the design of the Koppers type of oven are referred to. The American Koppers Company have decreased the width and increased the height and length of their ovens, and have attempted to strengthen the top horizontal flue by collecting the waste gases from a number of vertical flues into a small horizontal flue, whence they pass to two, three, or five "cross-over" flues over the arch of the oven and down the vertical flues on the other side to the regenerator. By dividing the gases through several cross-over flues the volume to be carried by the top horizontal flue is much decreased, and thus the size of the flue can be reduced and the structural strength of the oven is increased. The English and German Koppers companies have designed a chamber tapering upwards, the total taper of the walls being 2 inches. The difference in width compensates for the greater temperatures at the base of the flues and makes the rate of coking uniform throughout the charge.

E. W. Smith and F. S. Townend, *Manufacture of Oven Coke* (Gas World, 1925, vol. 82, Coking Section, pp. 27-32). In the ordinary coke-oven the length of the coking time necessary to carbonise the charge throughout causes the layer of coke near the oven walls to be subjected to a longer baking period than is necessary for its conversion into coke, and it becomes over-hard and incombustible. The practice of using narrower ovens, as lately developed on the Continent and in America, is advocated. Trials have shown that besides yielding a product of greater combustibility and of the required strength, the output of a 14-inch oven is 20 per cent. greater than from an 18-inch oven worked at the same temperature. Moreover, poorly coking coals will yield a satis-

factory coke in a narrow oven, when they will not do so in a wide oven, because the rapid heating promotes thermal decomposition of the resinic constituents, enabling them to exercise their binding properties, whereas slow heating in wide ovens causes these substances to distil without effecting the breakdown necessary for binding.

K. Bunte, *Production of Coke and its Uses* (Gas-und Wasserfach, 1924, vol. 67, pp. 721-724, 739-744, 758-760). The article describes practice in the manufacture of coke in Germany. The influence of the size of coal, the time and temperature of coking, and the mixing of coals on the quality of the coke produced is discussed.

T. Biddulph-Smith, *Flow of Gases in the Coke-Oven* (Paper read before the Coke-Oven Managers' Association: Iron and Coal Trades Review, Feb. 6, 1925, vol. 110, p. 220; Gas World, 1925, vol. 82, Coking Section, pp. 10-12). Experiments were carried out in which gases having distinct reaction were injected into the oven at various points, and samples of gases were drawn from various parts around the inlet and tested for the particular gas injected.

The results showed: (1) That either the plastic layer does not obstruct the passage of the gases, or the other physical conditions existing in the charge counterbalance its effect, since from the second to the seventh hour and from the eleventh to the sixteenth hour more SO_2 was found deeper into the charge, and beyond the plastic layer rather than directly above the point of entry. (2) That the path of travel of the main stream of gas was inward, with an upward tendency during the first third of the period. (3) That the path of travel of the main stream of gas was upward, with an inward tendency during the second third of the period. (4) That the gases during the last third of the period pass directly via the oven wall, until the last hour, when the direction is reversed and the gas passes up the middle of the charge.

J. D. Davis, *Calorimetric Apparatus for the Measurement of Reaction Heats at High Temperatures* (Fuel, Jan. 1925, vol. 4, pp. 38-44). An illustrated description of a twin calorimeter adopted for the measurement of the heat of carbonisation of coal. The apparatus was fitted with a complete water-jacket with adiabatic control.

H. Kohl, *The Carbonisation of Lignite and Sub-Bituminous Coals* (Canada, Department of Mines, Mines Branch, Investigations of Fuels and Fuel Testing, 1923, Ottawa, 1924, pp. 1-10). The report describes carbonisation experiments carried out on five different Alberta coals, in order to obtain information on the comparative yield and value of the carbonised residue or char as the main product, and of gas, tar oils, ammonia, etc., as by-products. The tests were carried out at both high and low temperature.

L. de Pritzbuier, *Distillation of Lignites* (Chimie et Industrie, May, 1924, pp. 258-261). The results of tests on the distillation of lignite are given.

E. Bury, *The Carbonisation of Coal, with Special Reference to the By-Product-Coking Process* (Fuel, Sept. 1924, vol. 3, pp. 307-314). The

paper is practically a reprint of one originally published in 1907, describing practice at that date in the carbonisation of coal.

Low-Temperature Carbonisation.—A. Thau, *A New Low-Temperature Carbonisation Process* (Glückauf, Mar. 28, 1925, vol. 61, pp. 369–371; Stahl und Eisen, Apr. 2, 1925, vol. 45, pp. 507–510). The difficulty in finding a market for the semi-coke produced in rotary furnaces has proved an obstacle in the development of the low-temperature carbonisation process. O. Dobbelsstein has now designed a new type of rotary furnace in which the process can be continuously carried on, the coal being packed in cells so as to prevent its movement during distillation. The furnace is timed to complete one revolution within the coking period of the coal, which is from three to five hours, the coke discharging on to a travelling belt, and the cells being continually refilled from a hopper as the furnace revolves. A very good lumpy porous coke results from the process.

The Vertical Retort for Low-Temperature Carbonisation (Stahl und Eisen, Oct. 16, 1924, vol. 44, pp. 1286–1290). The article describes the construction of the Meguin vertical retort and gives results of carbonising different kinds of coal therein.

O. Hubmann, *Low-Temperature Carbonisation in a Current of Gas* (Brennstoff-Chemie, 1924, vol. 5, pp. 333–337, 351–357). Practice in the carbonisation of raw lignite and recovery of tar in the process is described.

F. W. Sperr, *Practical Coal Carbonisation* (Mechanical Engineering, June 1924, vol. 46, pp. 329–333). Although low-temperature carbonisation offers great possibilities in the way of new processes and new products, no low-temperature process has proved a great success commercially. The most promising field for the application of such a process is in the treatment of feebly coking or non-coking coals.

A. R. Powell, *Practical Coal Carbonisation* (Mechanical Engineering, July 1924, vol. 46, pp. 389–394). The various types of retorts that have been designed for the low-temperature carbonisation of coal are briefly described, and the more important ones are also illustrated. The problems encountered in the distillation of both coking and non-coking coals are discussed.

N. Simpkin, *Some Aspects of Low-Temperature Carbonisation* (Engineer, May 1, 1925, vol. 139, pp. 487–488). Describes practice in low-temperature carbonisation and discusses the problems and difficulties in connection therewith.

C. H. S. Tupholme, *Low-Temperature Carbonisation* (Chemical and Metallurgical Engineering, Jan. 12, 1925, vol. 32, pp. 48–50). Particulars are given of the results of operating tests carried out on the Parker low-temperature carbonisation plant at Barnsley.

Low-Temperature Carbonisation (Department of Scientific and Industrial Research, Fuel Research Board, London, 1924, H.M. Stationery Office). The present report describes a test of the Parker

low-temperature carbonisation plant at Barugh, Barnsley, at the works of the Low-Temperature Carbonisation, Ltd.

T. W. S. Hutchins, *Low-Temperature Treatment of Bituminous Materials* (Paper read before the London Section of the Society of Chemical Industry: Iron and Coal Trades Review, Jan. 23, 1925, vol. 110, p. 132). The author reviews some of the more important conditions governing the satisfactory low-temperature treatment of bituminous material, and gives the results of tests carried out with the Fusion low-temperature retort.

C. Demeure, *The Manufacture of Coke by the Maclaurin Process* (Annales des Mines de Belgique, 1924, vol. 25, pp. 721-732). The plant and equipment of the Maclaurin Carbonisation Co., Ltd., Grangemouth, for the low-temperature carbonisation of coal is described.

F. Fischer and W. Krönig, *Increasing the Density of Semi-Coke without Applying Pressure* (Brennstoff-Chemie, 1924, vol. 5, p. 301). By the low-temperature carbonisation of mixtures of semi-coke and a swelling coal, uniform and very hard semi-cokes can be obtained. The density of the product is greater the smaller the particle size of the semi-coke and the greater the number of its pores. The rate of heating should be slower according to the more strongly swelling capacity of the coal used.

Recovery of By-Products.—*Recovery of Benzole from Coal and Coke-Oven Gases* (Report of the Benzole Research Committee, 1925: Iron and Coal Trades Review, May 1, 1925, vol. 110, p. 695). The work described in the Report was undertaken in order to obtain data for making a comparison between the active carbon and silica gel processes. It is concluded that for a gas containing 0.86 per cent. by volume of benzene vapour ($2\frac{1}{2}$ gallons per 12,000 cubic feet) and saturated with water vapour at 18°C .—that is, under conditions corresponding approximately with those of large scale practice, the maximum quantities of benzene taken up by saturation by active carbon and silica gel would be as follows:

	Grms. C_6H_6 adsorbed per 100 grms. of adsorbent.	Grms. C_6H_6 adsorbed per 100 c.c. of adsorbent space.
Active carbon	15-30	5.8-11.6
Silica gel	8-14	5.7-10.0

Although the active carbon shows a considerably higher adsorptive capacity for benzene than silica gel under benzole-recovery conditions, calculated on the weight of the adsorbent, the quantities of benzene taken up by active carbon and silica gel for the same volume occupied by the adsorbent are very nearly the same. The present position with regard to the application of the Bayer process to the recovery of benzole from coke oven gas is summarised.

Dry Cooling of Coke.—C. H. S. Tupholme, *Dry Cooling Coke with Inert Gas* (Chemical and Metallurgical Engineering, Oct. 13, 1924, vol.

31, pp. 574-575). An illustrated description of the Sulzer method of dry cooling coke. The coke is cooled in an air-tight receiver from about 2000° to about 400° F., the heat recovered being used for steam-raising.

Coking Tests of Coals.—H. Baehr, *Coal and Coke Tests with a View to Producing Coke of given Characteristics* (Brennstoff-Chemie: Iron and Coal Trades Review, Apr. 17, 1925, vol. 110, pp. 615-616). The object of coal and gas analyses, should be not merely to decide for what purpose the coke produced is suitable, but, by a careful study of the two together, to influence the coking process in the direction of producing coke of certain required properties. By thorough washing, compressing, blending rich coals of high volatile with less gassy coals, by addition of metallic oxides, or by regulating working temperatures, almost any desired results can be attained. To determine coking quality of a coal the following tests are of importance: moisture content, ash content, sulphur content, distillation test, bituminosity, and coking capacity. Of less importance are: chemical composition, calorific value, and microscopic structures.

It is chiefly the caking capacity which determines coking quality, and it is in direct proportion as bituminous matter in the coal is to the volatile constituents. The higher value of this ratio the lower is the fusion temperature of the coal, and the texture of a coke produced from a bituminous coal comparatively poor in gas is homogeneous. The general principles which determine coking practice as regards temperature, chamber width, and charging, are that low volatile coals can be coked at high temperatures in narrow chambers without compressing, while coals rich in gas give good coke only at low temperatures, in wide chambers, and with compressing. The only known method which gives any definite indication of the influence of the bitumen contents of a coal on its caking properties is the tar value according to the ordinary distillation test.

The whole coking problem may be regarded from another point of view, namely, choosing the coal to suit what is considered the best type of oven, instead of choosing the plant to suit the coal which is most readily available. The most economical oven has high but narrow chambers, and is worked at high temperatures. The chief factor in deciding the most suitable coal or coal mixtures is the bitumen-to-volatiles ratio. The influence of the coking temperature and the quality of coal on the pyro-chemical properties of the coke are considered and an apparatus and method for determining reactivity of coke are described.

C. Berthelot, *Unification of Methods for Testing Coal, Metallurgical Coke, and Briquettes* (Chimie et Industrie, May 1924, pp. 167-207). The physical and chemical tests of coal, coke, and briquettes are discussed.

E. C. Jeffrey, *Coal in Relation to Coke* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). An examination of a wide range of coals shows that a great part of the brown

matrix, which constitutes the mass of glistening coals with prismatic fracture, namely, bituminous coals and anthracites, is of woody origin. According to the author the value of a coal, from a standpoint of the coking industry, is in direct proportion, other things being equal, to its content of modified wood.

A number of coking experiments were carried out on Cretaceous lignites and fossil woods. In many cases the result was the formation of a quite typical coke, while in many instances no coke resulted. In the latter cases, a process of charring was obvious, but there was no liquefaction followed by the formation of coke. As the structural organisation of all the materials used in the experiments was purely woody, it follows that, in some instances, the wood had not undergone the chemical changes necessary to yield coke after being heated. It seems clear from the experiments that woody organisation is a fundamental feature of the coals that can be transformed into coke in the oven; it follows, therefore, that not only must wood be the predominant constituent of the original raw materials of the coking coals, but it must have attained an appropriate degree of chemical modification. It is entirely likely that where time and nature have not brought the woody raw materials of the coals into a condition fit for coking, the knowledge and ingenuity of man can take the place of the slow processes of nature. It seems entirely probable, accordingly, that in the process of time, and as a result of our increase of knowledge of the chemistry of coal, all combustible minerals of mainly woody origin can ultimately be transformed into utilisable coke.

E. Sinkinson, *Some Observations on the Transition of Coal to Coke* (Industrial and Engineering Chemistry, Jan. 1925, vol. 17, pp. 27-31). A study of the electric conductivity of coals of Spanish and British origin during coking has been extended to Pennsylvanian and other American coals. For coking coals a temperature of 500° to 530° C. is necessary before a sufficient quantity of free carbon is deposited to cause them to conduct electricity, but the conductivity temperature of a coking coal is increasingly higher as the amount of binding agent in the coal increases. Non-coking coals show appreciably lower conductivity temperatures than coking coals. In applying the conductivity method to a study of the thermal decomposition of coal, it was found that the gases first decompose and form a nucleus of carbon in a fine state of division. The carbon particles are assumed to be in so fine a state of division that forces of cohesion come into play and bind them into the foundational structure of coke. The humic bodies in coal are thought to be the principal source of the olefins and other unsaturated gaseous compounds from which free carbon is deposited within the range of temperatures found for the decomposition of coal.

H. E. Newall and F. S. Sinnatt, *Carbonisation of Coal in the Form of Fine Particles* (Fuel, Dec. 1924, vol. 3, pp. 424-434). Coal particles ground to an average diameter of 0.34 millimetre were allowed to fall through a vertically held silica tube maintained at a temperature of

600° C. in an inert atmosphere. The particles became spherical in shape and swelled considerably, becoming hollow. The term "cenosphere" is given to the hollow spheres. Cenospheres are reticulated, consisting of ribs over which is spread a thin transparent film or window, the windows and frames being the secondary structure of the coke. Prolonged heating renders the windows opaque. Vitrain and clarain both formed cenospheres, but durain did not.

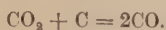
D. J. W. Kreulen, *Size of Particles in Coal Samples* (Brennstoff-Chemie, 1924, vol. 5, pp. 281-285). A continuation of the author's previous investigation on the influence of the size of particles of coal samples on the yield and character of the coke and on the ash content.

L. Gerbello, *The Ruhr Coals* (Metallurgia Italiana, Jan. 1925, vol. 17, pp. 3-11). The character, uses, and preparation of the Ruhr coals are described, with notes on the manufacture of coke and by-products.

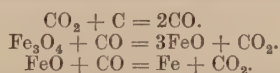
Combustion of Coke.—G. Weyman, *The Combustion of Coke in One Stage* (Journal of Society of Chemical Industry, Jan. 30, Feb. 6, 1925, vol. 44, pp. 47-60). The theory and phenomena of the combustion of coke are discussed. It is suggested that as the power of coke to combine with oxygen is adequately expressed by the ignition range the word "combustibility," which has no precise meaning, should be dropped. Coke is not a homogeneous substance, but is capable of undergoing preferential combustion. The ignition point may be defined as that temperature at which carbon and oxygen combine with formation of carbon dioxide, but with coke every particle does not come into reaction at the same temperature, and there is instead a range of temperature over which ignition is spread and incandescence does not occur till some time after the first formation of carbon dioxide. The state of ignition as evidenced by the first appearance of carbon dioxide may be called the primary ignition temperature, and the point at which the heat liberated is so high as to be out of control as far as the external heat supply is concerned, may be called the final ignition temperature. The ignition ranges of various cokes were determined by heating carefully graded samples in a vertical 1-inch silica tube, and are expressed in the form of curves.

J. P. Arend and J. Wagner, *The Reactivity of Coke* (Revue de Métallurgie, Oct. 1924, vol. 21, pp. 585-599). Many contradictory conclusions have of late been published on the subject of the reactivity of coke, by which term is meant the gasification of coke in carbon dioxide at blast-furnace temperatures, in distinction to combustion, which implies burning in air. Coke in the blast-furnace supplies the heat required for the necessary reductions and fusions. For this, a coke with high combustion temperature, and therefore not readily combustible, is required. Further, it rapidly yields the reducing gas, carbon monoxide, and this implies some degree of reactivity. Much confusion arises from these conflicting needs. A summary of current views is given,

and reactivity is subsequently defined as the equilibrium law of the reversible reaction :



In this connection reference is made to Boudouard's diagram, which has shown that the periods of reaction vary considerably at different temperatures and with different degrees of "reactivity." A method is described in which a greater relative constancy of reaction can be plotted, the apparatus employed being illustrated, and the results shown in tables and curves. These indicate that reactivity increases with porosity, but further that cokes having the same porosity, but derived from different sources, may vary in regard to activity up to as much as 15 per cent. This reactivity is influenced by the chemical composition of the coke and the methods by which it is manufactured. Extreme instances are afforded by a coke made from coal with 20 per cent. of wood sawdust added, the crushing resistance of which was only 29 kilogrammes per square centimetre, with a maximum porosity (56 per cent.), and a coal coked with 20 per cent. of pulverised coke, the crushing resistance of which was 60 kilogrammes, the porosity as low as 49 per cent., and the reactivity, 51.7, likewise low, as compared with a maximum reactivity of 68.5 in a 53.1 per cent. porous coke made by coking coal with the addition of 10 per cent. of Fe_2O_3 . This latter coke had a crushing resistance of 53 kilogrammes per square centimetre. The reactions which establish equilibrium and are reversible comprise :



This sequence of reactions and the temperature conditions under which they occur in the blast-furnace are discussed briefly. Broadly speaking, it will be found that at 1000°C . the relative reactivities of different fuels is 99 per cent. for wood charcoal; 70 per cent. for ordinary coke; 40 per cent. for beehive coke, and 20 per cent. for retort graphite. At higher temperatures each fuel develops further reactivity up to 100 per cent. each. At the high temperatures of the hearth, namely 2000°C ., all the fuels act similarly with the CO_2 derived from the primary combustion. The conclusions arrived at are as follows: A reduction in the carbon monoxide of the furnace gases and a corresponding saving in the coke consumption can be obtained by reducing the reactivity of the coke within the 1100° to 500°C . temperature interval. This can be achieved by using a very hard and compact coke in this interval, the reactivity of such a coke increasing at higher temperatures until at 1500°C . and over it attains the same degree of reactivity as the best cokes. The ideal type is American beehive coke, and American metallurgists have shown that the coke consumption increases enormously when by-product coke, the reaction of which with CO_2 is more intense, is used. The coke complying with the requirements can be made by rapidly heating the coal to 750° , followed by slower heating

to 1200° C. The reactivity of a metallurgical coke differs therefore essentially from the property of combustion in air, and it is possible, by using up-to-date methods, to produce a coke the reactivity of which shall be low at the temperatures of the reducing zone, and yet can burn rapidly in the oxygen of the blast at the tuyeres.

R. A. Sherman, *Combustibility of Blast-Furnace Coke* (Iron Age, Apr. 9, 1925, vol. 115, pp. 1043-1045). The author has carried out an investigation of the combustibility of various blast-furnace cokes and wood charcoal. The results show that the method of determination of coke combustibility by the estimation of the composition of the gases leaving a fuel bed of given thickness, of a given size of coke, and given rate of air supply, provides an accurate measure of the combustibility of the coke under those conditions. The combustibility can be calculated from the gas composition as a percentage of the maximum attainable combustibility. The combustibility of the fuels studied as measured at the top of a 12-inch fuel bed, burning pieces of a size from 1 to 1½ inch, with an air supply of 150 lbs. per hour, ranged from 59 per cent. for a pitch coke to 95 per cent. for wood charcoal.

Use of Waste Heat from Coke-Ovens.—I. C. F. Statham, *The Utilisation of Waste Heat and Surplus Gas from Coke-Ovens* (Paper read before the Midland Institute of Mining Engineers, Nov. 19, 1924: Iron and Coal Trades Review, Nov. 21, 1924, vol. 109, pp. 823-825). In the waste-heat type of oven the internal requirements vary from 70 to 100 per cent. of the yield of gas, leaving anything up to 30 per cent. as surplus, while in the regenerative type of oven only from 45 to 50 per cent. is required internally, leaving as surplus some 50 to 55 per cent. of the total yield. The surplus gas or waste heat may be employed for any of the following purposes, either singly or in conjunction with each other: (1) Steam raising by combustion in boiler furnaces; (2) generation of power by gas-engines; (3) industrial purposes, including town lighting. The different systems of utilising the surplus gas are dealt with and particulars are included of the results of tests on boilers and gas-engines.

J. W. Reber, *Waste-Heat and Gas-Fired Boilers* (Paper read before the Midland Junior Gas Association, Feb. 27, 1925: Iron and Coal Trades Review, Mar. 6, 1925, vol. 110, p. 395). This paper deals with two types of apparatus for steam-raising. The first section describes the utilisation of waste heat for the generation of steam, mainly in conjunction with coal-carbonising plants. In the second part the generation of steam by gaseous firing is dealt with, with special reference to a new type of gas-fired boiler.

That the iron and steel industries have recovered the waste heat from their furnaces for steam raising long before the gas industry, is mainly due to the fact that the combustion products from industrial furnaces are generally at a much higher temperature than those from carbonising plants. Most of the recent carbonising plants have been

provided with waste-heat boilers, and it can be assumed that in future this will become a standard practice.

The amount of steam raised from waste gases at a temperature of 800° to 900° F., with a fuel consumption of about 15 lbs. of coke per 100 lbs. of coal carbonised, will be about 500 lbs. per hour per ton of coal carbonised. To raise this amount of steam in a direct-fired boiler, assuming an evaporation of 7 lbs. of water per pound of coke, it would be necessary to use two-thirds of a cwt. of coke per day for each ton of coal carbonised, which amount would obviously be saved by using a waste-heat boiler.

The different types of waste-heat boilers and the theory of their operation are discussed. The author also deals with the amount of steam which could be generated from the waste gases of a carbonising plant, pointing out that with a given temperature drop, the quantity of steam could be calculated from the fuel consumption of the carbon-dioxide content of the waste gases. Assuming that the annual amount of coal carbonised in gasworks in Great Britain amounts to 15 million tons, the possible saving to be effected by waste-heat recovery would be approximately £3,000,000. An approximate balance sheet of a carbonising plant per ton of coal carbonised is included in the paper. A modified form of Cochran boiler adapted to gas-firing has been introduced by British Furnaces, Ltd. The form of combustion chamber in which the usual grate for coal firing has been replaced by a refractory bed is adapted for the application of surface combustion to steam raising.

IV.—LIQUID FUEL.

Oil Resources of the World.—A. W. Nish and H. G. Shatwell, *Fuel Oil Resources of the Future* (Journal of Institution of Petroleum Technologists, 1924, vol. 10, pp. 854–871). A short review is given of the present principal sources of petroleum. Among future resources, an important one consists in the abundant stores of bituminous material from which oil can be obtained by destructive distillation. Oil shales in various parts of the world are certain to prove one of the most valuable sources of oil in the future. Other sources whence oil can be obtained are lignites, peat, and coal. The most promising method of obtaining oil from coal is by means of the Bergius process, in which the coal is hydrogenated under very high pressures. Experiments at Birmingham University have shown that very little change takes place if the material is heated alone with hydrogen. If, however, the coal be mixed with a substance like phenol, or a high-boiling mineral oil, and subjected to hydrogenation considerable absorption of hydrogen occurs, and a large proportion of the coal becomes liquid. A description of the process is given.

Argentina.—C. M. Hunter, *The Oilfields of Argentina* (Journal of Institution of Petroleum Technologists, 1924, vol. 10, pp. 829-845). A survey of the potential oilfields of Argentina shows that the prospects of developing an important oil industry in that country are very promising. In the southern coastal fields in the district around Comodoro Rivadavia the annual production is now about 750,000 tons of oil. Increasing regard is now being paid to other and higher grade oilfields, notably those in the district of Neuquen, where numerous favourable geological structures are found, and new wells are being drilled.

Australia.—*The Power Resources of the Commonwealth of Australia and the Mandated Territory of New Guinea* (Report to the World Power Conference, London, 1924. Compiled by the Institution of Engineers, Australia, Sydney, 1924). Petroleum has not yet been found in Australia. Apart from comparatively small quantities of shale oils and tar oils locally produced, liquid fuels are entirely imported from the East Indies and the United States. In relation to the extent of coal deposits, those of oil shale in Australia at present known are very small. Deposits of oil shale are known in New South Wales, Tasmania, Queensland, and Western Australia.

France.—A. Werenfels, *Exploration for Petroleum in the Limagne, France* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). The geology of the Limagne, the surface indications of petroleum, and recent exploration work are briefly discussed. According to the author, none of the wells already drilled were properly located, therefore the oil possibilities of the Limagne cannot be considered as having been adequately tested.

Japan.—A. T. Coumbe, jun., *Petroleum in Japan* (Petroleum Times, 1924, vol. 12, pp. 661-663). The principal source of petroleum is the petroliferous areas along the western coast of the main island of Honshu, in the Niigata district of Echigo Province, and in the Akita district of Ugo Province. A description of each field, together with figures of production, and characteristics of the oils, are given.

Mexico.—W. A. VerWiebe, *The Stratigraphy of the Petroliferous Area of Eastern Mexico* (American Journal of Science, 1924, vol. 8, pp. 277-295, 385-394, 481-502). The geology of the oil-bearing region of eastern Mexico is described; the area involved extends from the Rio Grande river on the north to Punta-Piedras (45 miles north of Vera Cruz) on the south, and from the Gulf of Mexico on the east to the edge of the central plateau of Mexico on the west. The region thus consists of a strip of coast line with an average width of 60 miles and a length of approximately 450 miles.

Russia.—Aldebert, *The Present Position of the Baku Petroleum Industry* (Mémoires de la Société des Ingénieurs Civils de France, Jan.—

Mar. 1924, pp. 87-112). A review of the industry, contrasting conditions, plant, practice, wages, and labour conditions in 1913, and those now prevailing under Soviet administration. Production in tons has fallen from 7,305,000 in 1913 to 2,731,000 tons in 1922. The figures for 1923-24 show a slight increase.

Saghalien.—H. Nishihara, *Petroleum in North Saghalien* (Engineering and Mining Journal-Press, Mar. 14, 1925, vol. 119, pp. 449-450). The geological formation of these deposits is briefly described.

United States.—W. S. W. Kew, *Geology and Oil Resources of a part of Los Angeles and Ventura Counties, California* (United States Geological Survey, 1924, Bulletin, No. 753). The report describes the stratigraphy and structure of the area lying in the southernmost part of the California coast ranges, directly east of the San Gabriel Mountains and north of the Santa Monica Mountains.

Legraye, *Note on the Petroleum Resources of California* (Revue Universelle des Mines, Nov. 1, 1924, vol. 4, Series 7, pp. 149-155). The oil deposits of California, the origin of which is briefly discussed, occur wholly in the organic schists of the State. Their stratigraphy is described. The Miocene formations, which contain the famous Monterey shale, are the most important. The oil belongs for the most part to the ethylene series and has an asphaltic base. Its calorific value varies from 10,200 to 10,400 calories. The oil zones are extremely productive, and have been intensively exploited. The 1923 production averaged 300 million barrels. The falling off in yield at operating wells varies annually some 10 to 25 per cent., but the opening of new wells more than makes good this reduction, and the general resources show no signs of diminution.

F. Reeves, *Geology and Possible Oil and Gas Resources of the Faulted Area South of the Bearpaw Mountains, Montana* (United States Geological Survey, 1924, Bulletin, No. 751-C.).

A. E. Fath and G. F. Moulton, *Oil and Gas Fields of the Lost Soldier—Ferris District, Wyoming* (United States Geological Survey, 1924, Bulletin No. 756).

Venezuela.—A. H. Garner, *Oil Geology of Northern Venezuela* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). Oil has been found in many sands in formations ranging in age from Cretaceous to the Quaternary. The most prolific source of oil is probably the cretaceous shales and limestones, from which the oil appears to have migrated into overlying porous beds.

Oil Shales.—H. G. Shatwell, A. W. Nash, and J. I. Graham, *Somerset Shale Oils* (Journal of Institution of Petroleum Technologists, 1924, vol. 10, pp. 872-883). These shales outcrop for about ten miles along the coast in the vicinity of the Blue Anchor, and extend inland for a

distance of one to three miles. The shales occur in beds ranging from 1 to 20 feet in thickness, and they have an average specific gravity of 2.4, with ash 70 to 73, moisture 3.5, volatile matter 23 to 28, and sulphur 1.70 to 4.52 per cent. The yield of oil is about half that of the average yield of the Scottish shales, the total amount obtained from 1 ton of Somerset shale being 5 to 10.4 gallons, ammonium sulphate from 4 to 6 lbs., and gas from 1200 to 1900 cubic feet.

J. C. Dawson, *Oil Shales* (Bulletin of the Canadian Institute of Mining and Metallurgy, Jan. 1925, pp. 26-59). The distribution, origin, and nature of oil shale and its distillation are dealt with.

S. D. Kirkpatrick, *What About Oil Shale?* (Chemical and Metallurgical Engineering, Oct. 20, 1924, vol. 31, pp. 611-615). A brief survey is given of the resources of oil shale in the United States, and the history of their development is outlined. The economic and technical problems in the development of oil shale are discussed by the author in the following articles:

Economic Problems in Oil Shale Development (Chemical and Metallurgical Engineering, Oct. 27, 1924, vol. 31, pp. 651-655).

Oil Shale Technology in the Making (Chemical and Metallurgical Engineering, Nov. 2, 1924; vol. 31, pp. 688-692).

S. D. Kirkpatrick, *American Progress in Retorting Oil Shale* (Chemical and Metallurgical Engineering, Nov. 17, 1924, vol. 31, pp. 770-774). The principal American processes proposed for the retorting of oil shale are tabulated, and an account is given of the operation of the Catlin and Brown retorts.

G. W. Wallace, *Production of Shale Oil by the N.T.U. Process* (Chemical and Metallurgical Engineering, Feb. 9, 1925, vol. 32, pp. 237-239; Chemical Age, Feb. 28, 1925, vol. 12, pp. 196-199). The author describes the operating results of the plant of the N.T.U. Company of California, utilising internal combustion for the distillation of shale. The generator holds a charge of about 40 tons of shale. The outlet for the oils and gases is located at the bottom of the generator and connects with a fan type gas exhauster on the suction side.

The generator is charged with shale and ignited at the top. By a down draft through the column of shale a zone of combustion is set up at the top of the column of shale. The products of combustion in travelling down through the shale maintain a zone of distillation which travels progressively downward from the top to the bottom of the chamber below the fire. The oil as it is produced from the shale either condenses in the cool shale underlying the zone of distillation or is carried by the gases to the usual standard condensing and scrubbing apparatus, where it is recovered and added to the oil condensed in the generator and pipe lines. The air used to maintain combustion is modified by returning some of the gaseous products of combustion from the outlet of the last scrubber, thus reducing the oxygen content of the medium of combustion, thereby lowering the temperature of the zone of combustion. Particulars of operating costs are given.

A. W. Homberger and F. M. Shipman, *Distillation of New Albany Oil Shales* (Quarterly of the Colorado School of Mines, Jan. 1925, vol. 20, No. 1, pp. 1-7). The authors have studied the New Albany oil shales of Lower Indiana, the products derived from them by the various methods of distillation, and the properties of the products obtained.

A. A. Swinnerton, *The Hartman Oil Shale Retort* (Canada, Department of Mines, Mines Branch, Investigations of Fuels and Fuel Testing, 1923, Ottawa, 1924, pp. 54-64). The Hartman retort for the distillation of oil shale is described and the results of operating tests are given.

Mining and Refining of Petroleum.—W. W. Cutler, jun., *Estimation of Underground Oil Reserves by Oil Well Production Curves* (United States Bureau of Mines, 1924, Bulletin No. 228). The report reviews, in the light of recent experience, the use of production-decline curves in estimating the future production of oil from wells. It deals with the estimation of the reserves of recoverable oil in properties already producing or in those adjacent to them, takes cognisance of the physical laws governing expulsion of oil from oil sands, and shows how the production-decline curve can be made to utilise these laws in estimating reserves and rates of production.

L. C. Uren, *Increasing Production of Petroleum by Increasing Diameter of Wells* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). In this paper the increase in the rate of production of oil from wells with increased diameter is demonstrated from both the physical and mathematical points of view and by experimental evidence. It appears that if a well is reamed to a diameter of 20 feet within the oil sand, its production will be approximately doubled. A novel method is proposed for forming and supporting a cavity of such proportions within the oil-producing stratum.

National Standard Petroleum Oil Tables (United States Bureau of Standards, 1924, Circular No. 154). The tables given are based on an investigation of American petroleum oils carried out by the Bureau of Standards, and the arrangement is largely according to the recommendations of a committee appointed by the American Petroleum Institute. In order to overcome the confusion that has existed in the petroleum-oil industry by reason of the use of two so-called Baumé scales for light liquids, it was agreed to recommend that in future only the scale based on the modulus 141.5 be used in the petroleum-oil industry, and that it be known as the A.P.I. scale. The relation of degrees A.P.I. to specific gravity is expressed by the formula :

$$\text{Degrees A.P.I.} = \frac{141.5}{\text{sp. gr. } 60^{\circ}/60^{\circ} \text{ F.}} - 131.5$$

A certain degree of accuracy in the determination of the temperature is essential in order to have results that are comparable with the determination of the gravity of the oil. Tables I., II., and III. give the degrees A.P.I., the volume, and the specific gravity of oil at 60° F. from

the values observed at other temperatures. Tables IV. and V. give the relation between specific gravity, degrees A.P.I., pounds per gallon, and gallons per pound. Table VI. gives the degrees A.P.I. (modulus 141.5) corresponding to degrees Baumé (modulus 140).

R. H. Brownlee, *Developing Modern Equipment for Cracking Petroleum* (Chemical and Metallurgical Engineering, Nov. 24, 1924, vol. 31, pp. 812-817). An account is given of the early difficulties met with by W. M. Burton and his co-workers in the cracking of heavy oils. A description is also given of the Cross, Dubbs, and Fleming processes.

R. H. Brownlee, *What About the Future of the Cracking Process?* (Chemical and Metallurgical Engineering, Dec. 1, 1924, vol. 31, pp. 848-852). The author discusses the probable developments in the cracking of petroleum, and describes the Isom, Holmes-Manley, Rittman, Greenstreet, Forward, McAfee, and Ellis processes.

R. E. Gilmore and R. V. Rosewarne, *Report on the Ramage Process* (Canada, Department of Mines, Mines Branch, Investigations of Fuels and Fuel Testing, 1923, Ottawa, 1924, pp. 65-83). The Ramage process for converting heavy petroleum oil products into lighter oils suitable for use as fuel in internal combustion engines is described and illustrated. A description is given of the plant of the National Oil Refineries at Montreal East, and results of operating tests are included.

J. C. Morrell, *Operating a Modern Cracking Plant* (Chemical and Metallurgical Engineering, Dec. 29, 1924, vol. 31, pp. 1006-1010). The author describes the Dubbs oil-cracking process, and discusses some of the commercial results obtained.

Bergius Method of Hydrogenation of Coal.—H. I. Waterman and J. N. J. Perquin, *Hydrogenation by the Bergius Method* (Journal of the Institution of Petroleum Technologists, 1924, vol. 10, pp. 670-677). A summary of the results of experiments is given in which the Bergius method for the conversion of coal into oil by hydrogenation is applied to asphalt and paraffin wax with promise of success. The experiments are still being pursued.

H. G. Shatwell, *The Hydrogenation of a Gas Oil* (Journal of the Institution of Petroleum Technologists, 1924, vol. 10, pp. 903-911). The author's investigations lead to the conclusion that the hydrogenation of an ordinary gas oil under high pressures and at temperatures between 400° and 420° C. results in the production of substantial yields of gaseous and low-boiling hydrocarbons. The mechanism of the reactions involves initial decomposition or cracking, followed by hydrogenation of the unsaturated hydrocarbons produced, in which the concentration of hydrogen is a determining factor.

O. E. Mott and E. A. Dunstan, *Note on the so-called Hydrogenation of Gas Oil* (Journal of the Institution of Petroleum Technologists, 1924, vol. 10, pp. 911-913). Experiments were made with the object of comparing the results obtained by the Bergius method with those obtained by cracking gas oil at the same temperatures and pressures. The

cracking experiments were conducted under the pressure of an inert gas (nitrogen), and steam was also tried. The temperature was in each case maintained at 405° to 420° C. for about 3 hours, and a pressure up to a maximum of 135 atmospheres was employed. Nitrogen was found to give much the same result as the hydrogen under the Bergius system, and it is concluded that hydrogen has little or no effect in hydrogenating or preventing dehydrogenation.

H. I. Waterman and J. N. J. Perquin, *Hydrogenation in the Petroleum Industry* (Journal of the Institution of Petroleum Technologists, Feb. 1925, vol. 11, pp. 36-50). The continuation of experimental work is described. Comparative experiments show that Berginisation has various advantages over heating in absence of hydrogen under high pressures (cracking). The process must be considered as a combined cracking and hydrogenation process. The useful feature of cracking, the breaking down of hydrocarbon molecules, remains, but is made more regular, while the products are obtained in a more stable condition on account of the addition of hydrogen, so that extensive polymerisation and formation of coke are avoided, but the saturation of unsaturated hydrocarbons already present is not probable. On the other hand, the loss of hydrogen from residues which takes place in the ordinary process of cracking is prevented by Berginisation.

H. G. Shatwell and J. I. Graham, *The Hydrogenation and Liquefaction of Coal* (Fuel, Feb. 1925, vol. 4, pp. 75-81). From experiments it is concluded that the possibility of hydrogenating and partially liquefying a constituent of a typical British bituminous coal without the aid of added catalysts has been definitely established, and a substantial yield of oil can be obtained. The nature of the liquid has not been fully investigated, but it contains oxygen and is nearly free from sulphur. The next problem is to determine whether the oxygen can be eliminated by further hydrogenation and hydrocarbons thereby produced

Natural Gas.—R. T. Elworthy, *Natural Gas in Alberta* (Canada, Department of Mines, Mines Branch, Investigations of Mineral Resources and the Mining Industry, 1923, Ottawa, 1924, pp. 16-46). The situation of the chief fields is described, with brief reference to the geological formations underlying them and the manner in which the gases may be used to the best advantage. The character of the field work is referred to, followed by a description of the chief gas fields. The possibilities of natural gas gasoline production, the manufacture of carbon black, and the extraction of helium are also considered.

V.—ARTIFICIAL GAS.

Gas-Producers.—P. Appell, *Comparative Tests on a Siemens Producer Transformed by the Addition of a Grate Formed of Hollow Rotating Bars* (Chaleur et Industrie, June 1924, vol. 5, pp. 312-313). The new

grate consists of firebars formed by hollow tubes pierced on their upper half-diameter with holes for the air or steam blast, and provided, as to their lower half-diameter, with lugs which engage with a rack, thus enabling them to revolve, to a limited extent, in alternate directions. This deflects the air current and so serves to make combustion more uniform and to prevent lumps and clinker forming so as to interfere with the operation of gasification. The efficiency of such a grate is said to be 86.3 per cent. as compared with 64.4 per cent. in an ordinary Siemens gas-producer.

Mechanical Gas-Producer (Engineering, Jan. 9, 1925, vol. 119, pp. 37-40). The article gives an illustrated description of the new model of the Wellman mechanical gas-producer. The rotating parts are the producer body and the ashpan. The new type is made in two sizes, the larger one having an efficient gasifying capacity ranging from 2500 lbs. up to 4000 lbs. of bituminous coal per hour. In the smaller type the capacity range is from 1500 to 2750 lbs. per hour. Sectional drawings are shown and particulars of the method of operation are given.

K. Huessener, *The Slagging Producer in Steelworks* (Iron and Steel Engineer, 1924, vol. 1, pp. 457-464). The cost of gas made in a slagging producer compares favourably with oil firing, and is considerably lower than that of coal-producer gas. The range of fuels which can be used in the slagging producer is limited, the best fuel being domestic or blast-furnace coke.

Gas-Power Plant Installation at the Works of the National Gas-Engine Company, Ltd., Ashton-under-Lyne (Iron and Coal Trades Review, Jan. 9, 1925, vol. 110, pp. 53). The installation comprises a Mond by-product recovery gas-producer plant. The gas is used in eight National gas-engines of a total capacity of 2500 brake horse-power. Two of the producers are operated on the semi-low temperature system. Particulars are included of operating costs.

M. Laffargue, *Chemistry and Rational Operation of Gas-Producers* (Chimie et Industrie, May 1924, pp. 230-233).

A. B. Huyck, *Gas-Producer Theory and Practice* (Blast-Furnace and Steel Plant, Dec. 1924, vol. 12, pp. 542-545). A general exposition of the principles of modern gas-producers and practice in working them.

Producer-Gas.—R. V. Wheeler, *Gaseous Fuels for Furnace Heating* (Journal of the West of Scotland Iron and Steel Institute, Dec. 1924, vol. 32, pp. 24-26). An attempt is made to evaluate gaseous fuels with respect to their use in furnaces, more particularly steel melting and reheating furnaces. The subject is approached from the point of view of the chemist, and the chemical and physical properties of the gases are discussed. One of the chief characteristics of a producer-gas rich in hydrogen is the tendency to yield a short flame when it is burnt in a furnace, a tendency which, in extreme cases, causes the gas to burn within the ports to the detriment of the brickwork. A measure of this

tendency, for producer-gases of different compositions, is given by comparison of the relative maximum speeds of uniform movement of flame under standard conditions. These speeds can be calculated from the analyses of the mixtures. Examples are given in the following table:

Steam saturation temperature of blast.			
Degrees C.	45	70	80
Average analysis of gas, per cent. :			
CO ₂	2·35	9·25	13·25
CO	31·60	20·85	16·05
H ₂	11·60	19·75	22·65
CH ₄	3·05	3·45	3·50
N ₂	51·40	46·70	44·55
Relative speeds of uniform movement of flame (50 per cent. mixture with air) under standard conditions :			
Centimetre per second	75	110	150

A furnace charge receives the heat developed by a burning gas in two ways : in a small degree, by direct conduction from a portion of the flame itself and from the hot products of combustion ; and, to a greater extent, by radiation from the flame and from the walls and roof. Although carbon monoxide and hydrogen have the same calorific value, their flames do not radiate the same amount of heat, but a carbon monoxide flame radiates nearly $2\frac{1}{2}$ times as much heat as a hydrogen flame burning the same volume of gas. Hydrogen when mixed with air is far more susceptible than carbon monoxide to the catalytic effect of heated surfaces, and for this reason the destruction of brickwork in a steel-melting furnace is more rapid when the producer gas contains a high proportion of hydrogen. In the use of coke-oven gas for furnace heating, methane and, to a lesser degree, carbon monoxide stabilise the flame ; and hydrogen and carbon monoxide, by reason of their wide limits of inflammability, ensure the "adaptability of the gaseous fuel." The chief advantage claimed for coke-oven gas is that the working temperature of the furnace can be increased so that about 25 per cent. increased output can be obtained ; while difficulties encountered in its use are the tendency of the flame to rise to the furnace crown and fuse the brickwork, and the low luminosity of the flame (owing to the freedom of the gas from tarry vapours), which renders difficult observation of the conditions in the furnace. Both difficulties can be overcome by using tar in addition to the gas ; and, since the use of coke-oven by-products in this manner dispenses with producers and simplifies the construction of the furnaces, no doubt the practice will spread.

A. Loschge, *The Gasification of Raw Lignite* (Zeitschrift des Vereines Deutscher Ingenieure, Jan. 3, 1925, vol. 69, pp. 1-8). Trials in the gasification of broken unscreened raw lignite in the Heller producer show favourable results. The lignite contained about 24 per cent. carbon, 9·8 per cent. oxygen 7·7 per cent. ash and 54·9 per cent. moisture. A power gas with 1100 to 1280 calories per cubic metre was obtained.

J. Weiss and H. Becker, *The Use of Raw Rhenish Lignites in Industry*

(Chaleur et Industrie, Nov. 1924, pp. 573-578). Describes the use of raw Rhenish lignites for producer work and the production of gas generally, with data as to its behaviour, the tar and by-products content, and the economic aspects of its use in various applications in metallurgy and other industries.

D. J. Demorest, *Producer-Gas as an Industrial Fuel* (Chemical and Metallurgical Engineering, Oct. 13, 1924, vol. 31, pp. 578-581). The author describes the industrial utility of producer-gas.

A. C. Ionides, jun., *Gas Firing* (Transactions of the Society of Engineers, 1924, pp. 53-70).

Water-Gas.—D. J. Demorest, *Blue Water-Gas Offers Industrial Fuel Economies* (Chemical and Metallurgical Engineering, Dec. 8, 1924, vol. 31, pp. 887-890). The author discusses the economics effected by the use of blue water-gas. Owing to its freedom from tar, soot, and vapours, it is of the highest value for welding and similar work where cleanliness is desirable.

Use of Coke-Oven Gas.—*Eickworth Patent Rotary Gas Burner* (Iron and Coal Trades Review, Nov. 21, 1924, vol. 109, pp. 838-839). Illustrated particulars are given of this burner designed for burning coke-oven gas or blast-furnace gas under boiler or stoves. The results of tests carried out with this burner at Hoersch are also included. The burner when in operation transforms the pressure energy of the gas into work, by causing the gas to drive a turbine wheel, which in turn drives a fan fixed upon the same spindle. This fan draws the whole of the air required for combustion into the combustion chamber without the aid of chimney draught. Any alteration in gas pressure alters the speed of the turbine, and thereby causes the fan to take in a greater or smaller quantity of air as the case may be. The proportions of gas and air therefore must always remain under the same conditions.

R. S. McBride, *City Gas from Coke-Ovens* (Chemical and Metallurgical Engineering, Nov. 10, 1924, vol. 31, pp. 735-736). Illustrated particulars are given of the coking plant in operation at Battle Creek, Michigan, for supplying town gas. The plant is a pioneer effort, and is the first attempt to meet the requirements of a city with a widely fluctuating gas demand by means of a small battery of coke-ovens. The plant consists of a battery of eleven Becker type coke-ovens, each with a capacity of 6.5 tons, and a coking period of twelve hours. The ovens are fired either by surplus gas or producer-gas.

Producer-Gas from Peat.—J. Steinert, *Economic Prospects of Utilisation of Peat* (Zeitschrift für Angewandte Chemie, 1925, vol. 38, pp. 61-67). Discusses the drying and preparation of peat and its suitability as a fuel for metallurgical work and gas-producers.

VI.—COAL-WASHING AND HANDLING.

Coal-Washing.—A. France-Focquet, *Contribution to the Study of Rheowashers* (Revue de l'Industrie Minérale, Mémoires, Jan. 15, 1925, pp. 23–42). It is a fault underlying many systems and processes of coal-washing to assume the raw coal to consist wholly of pure coal intermingled with pure shale or stone, and the principles involved are built on this assumption and on the respective density of these bodies. The rheowasher, the theory and construction of which are fully illustrated and explained, is designed to deal in turn with all the particles of intermediate densities of which the unwashed material actually consists. Flow sheets and diagrams of the grading results accompany the paper.

Rheolaveur Coal-Washing Plant in Germany (Iron and Coal Trades Review, Nov. 28, 1924, vol. 109, pp. 866–867). An abstract of the paper by E. Dupierry describing the various methods used in Germany for preparing coal for the market, with special reference to the Rheolaveur method.

Chataignon, *Flotation, and its Application to the Washery Waste Dumps at Noeux* (Revue de l'Industrie Minérale, Mémoires, July 15, 1924, pp. 361–372). After a consideration of the principles involved in flotation processes generally, the details of the method employed by the Vicoigne, Noeux, and Drocourt Colliery Company, Nord, France, are described. The washery waste tips are estimated at 2,500,000 tons, composed entirely of sludge, with an average ash content of 65 per cent. A flow sheet is given. One hundred tons of concentrates are obtained per 24-hour day with a plant laid down in 1923, the ash content being about 20 per cent., and the moisture 15 per cent. The plant is to be extended so as to produce 1000 tons per day.

C. Berthelot, *The Washing of Coal by Flotation; its Object, Advantages, and Mode of Application* (Bulletin de la Société d'Encouragement, Jan. 1925, vol. 137, pp. 15–52). The theory and methods of coal-washing by flotation are discussed with considerable detail, and tables of the results of grading, showing the recovery of usable coal and percentages of ash in the product and in the residues are given. The coking of the concentrate is also described, sulphur elimination being more particularly dealt with. The plant and operations of the leading types are illustrated, including the France system, the Trent system, the Elmore and the Minerals Separation Company's process, and the Kleinbentink, Ekof, and Coppée systems. The application of flotation methods to existing coal-washery plants, and the cost and working expenses of such appliances, are discussed.

H. Bonnardeaux, *The Flotation of Coals* (Revue Universelle des Mines, Mémoires, June 1, 1925, vol. 5, pp. 26–33). A brief account of the principles on which flotation methods are based, with details of the first cost, and the labour and maintenance charges which have to be

incurred in working a unit capable of treating 52 tons of washery waste to obtain a 75 per cent. yield of recoverable fuel residues.

F. A. Downes, *The Cleaning of Coal by the Conklin Flotation Process* (Fuel, Nov. 1924, vol. 3, pp. 400-403). The flotation medium employed in the Conklin process is a mixture of water and very finely ground rock, so finely ground that the particles remain in suspension. A continuous separation of the coal from its impurities is accomplished by its flotation in the bath, the specific gravity of which is maintained between that of the coal and the rock.

L. Dessagne, *The Application of Froth Flotation to Coal-Washing* (Fuel, Sept. 1924, vol. 3, pp. 320-327; *Technique Moderne*, 1923, vol. 15, p. 554). A description is given of the froth flotation process and the mode of operation.

O. Schäfer, *Treatment of Coal Sludge by Froth-Flotation Processes* (Stahl and Eisen, Jan. 1, 8, 1925, vol. 45, pp. 1-7, 44-51). The article describes the application of froth-flotation processes to the recovery of coal from the sludge which collects in the settling tanks of coal-washing plants. The drying operation is much simplified if the recovered coal is graded before drying, and, as it contains 50 to 70 per cent. of water, mechanical methods or drying furnaces have to be used. Tables and diagrams are given showing the costs of the flotation process as carried out at five German collieries. The concentrates recovered show from 5 to 9 per cent. of ash.

H. M. Chance, *The Chance Sand-Flotation Process as Applied to the Washing of Coal* (Fuel, Aug. 1924, vol. 3, pp. 269-275). A description of the operation of the process on a commercial scale, based on a three years' practical experience.

A. Czermak, *Recovery and Utilisation of Small Coal* (Berg- und Hüttenmännisches Jahrbuch, 1925, vol. 73, pp. 1-24). The article deals with modern methods of coal-washing, and in particular the recovery of slack from sludge by the flotation process.

E. L. Warburton, *Wet Washing of Coal at Corbin, British Columbia* (Bulletin of the Canadian Institute of Mining and Metallurgy, Dec. 1924, pp. 933-941).

Washing "Fines" Coal at Kingsbury Colliery (Iron and Coal Trades Review, Apr. 3, 1925, vol. 110, p. 551). The general arrangement of the coal-washing plant at Kingsbury Colliery, designed on the British Baum principle for dealing with a comparatively small tonnage of "fines," is described.

E. C. Evans, *Coke Purity* (Fuel Economy Review, Oct. 1924, vol. 4, pp. 29-32). The deleterious effect of impurities in coke on blast-furnace operations is pointed out. Developments in the flotation system and dry-cleaning of coal are dealt with.

Screening Plant at Ogilvie Colliery (Iron and Coal Trades Review, Jan. 30, 1925, vol. 110, pp. 169-170). The coal-screening plant in operation at the Ogilvie Colliery of the Powell Duffryn Steam Coal Co. is described.

Coal Briquetting.—*Briquetting Tests in Alberta* (Fourth Report of the Scientific and Industrial Research Council of Alberta: Colliery Guardian, Nov. 7, 1924, vol. 128, pp. 1190–1191). The report contains particulars of briquetting tests carried out with Alberta coals, and a study of the physical properties of different binders.

Storage of Coal and Spontaneous Combustion.—The following papers were presented at a general discussion on *Storage of Coal and Spontaneous Combustion* before the American Chemical Society, Sept. 8–13, 1924. (Journal of Industrial and Engineering Chemistry, Feb. 1925, vol. 17, pp. 115–130).

S. W. Parr and R. T. Milner, *The Oxidation of Coal at Storage Temperatures*.

S. W. Parr and E. R. Hilgard, *Oxidation of Sulphur as a Factor in Coal Storage*.

S. W. Parr and C. C. Coons, *Carbon Dioxide as an Index of the Critical Oxidation Temperature for Coal in Storage*.

S. W. Parr, *Deterioration and Spontaneous Combustion of Coal in Storage*.

N. R. Beagle, *Deteriorations of Midwest Coals under different Storage Conditions—Effect on Burning Qualities*.

J. D. Davis and J. F. Byrne, *Spontaneous Combustion of Coal; Characteristics shown by an Adiabatic Calorimeter*.

PRODUCTION OF IRON.

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I.—MANUFACTURE OF PIG IRON.

Blast-Furnace Design and Equipment.—A. Korevaar, *Future Development of the Shape of the Blast-Furnace* (Iron and Coal Trades Review, Apr. 10, 1925, vol. 110, pp. 577-579). Evolution in the shape of the blast-furnace has developed slowly but decidedly in the direction of steepening the angle and reducing the height of the bosh. The author attempts to advance the existing knowledge on this point, basing his arguments on the views of Johnson. A new theory is developed by the author explaining the favourable working of the blast-furnace with low as well as with steep boshes. A connection is found between the shape of the furnace and its working, based on the slow travelling of the gases along the wall, and not on the constant gas-velocity principle. The author rejects the theory that the shape of the furnace has any relation to the constant velocity of the gases. At the top of the bosh where the cones of the shaft and the bosh meet, a dead corner is formed where the gas velocity is slow. In the dead corner there is not enough heat to completely smelt the slags, and consequently they remain in a sticky condition and adhere to the furnace walls. The result is a closer contact between slag and wall, and consequently an increased transmission to the surroundings, which makes the adhering slags still more cold and hard. This is the beginning of the formation of the scaffolds, resulting finally in "hanging" in the blast furnace. It may be concluded that the blast furnace should be designed so as to reduce the formation of a dead corner to a minimum. This can be done by lowering as well as steepening the bosh. Another factor ruling the shape of the bosh is found in the support of the stock column. For not only with a steeper bosh, but also with a shorter one, the support of the stock column is diminished. With bigger furnaces the task of supporting the stock column has been partly taken over by the increased air pressure, which is good for driving the furnace, because the air is liable to be regulated, so that, when the stock column is resting for a greater

part on the blast, the resistance against the descending stock column becomes more readily controllable by the furnaceman. The chances of irregularities will diminish because the elastic resistance of the gases will give less cause to jam the stock column in the furnace than the immovable resistance of the bosh walls. If this conclusion is right it may be predicted that the development of the shape of the furnace is not yet finished, for with furnaces built with perpendicular bosh walls the dead corner would be quite harmless, and the bosh walls would be completely relieved of support of the stock column. For these reasons we may perhaps expect that the shape of the blast-furnace will develop further until the bosh with perpendicular walls has been built.

S. P. Kinney and F. B. McKenzie, *Proposed Hearth and Bosh Construction* (Iron Age, Feb. 12, 1925, vol. 115, pp. 476-478). Combustion of coke takes place directly in front of the nose of each tuyere. The combustion space in the front of the nose of each tuyere is spherical, tubular, or conical in shape, and extends toward the centre of the hearth of the furnace for a distance of approximately 36 to 46 inches from the nose of the tuyere. Since the zones of combustion are approximately constant in size and depth of penetration in all furnaces, there is a circular area left in the centre of the hearth plane of each furnace where no combustion is taking place. The circular area forms the base of a conical volume which is in contact with the molten iron and slag in the bottom of the furnace, and this zone extends well up into the bosh. Since combustion is not taking place in the centre area or cone, its temperature is much lower than that of the zones directly in front of the tuyeres. The central cone affords a space where gas reactions, such as direct reduction and the formation of cyanides, may proceed at the expense of heat, and therefore carbon. It also has a cooling effect on the hearth area as well as on the molten slag and metal in the crucible. To overcome the above difficulties the position of the tuyeres around the hearth area should be rearranged. The authors suggest a hearth of elliptical or similar section and enumerate the apparent advantages of the proposed design.

J. M. Ringquist, *Recent Mechanical Chargers for Blast-Furnaces* (Paper read before the Cleveland Institution of Engineers, Feb. 9, 1925 : Iron and Coal Trades Review, Feb. 20, 1925, vol. 110, pp. 293-295). The author describes and illustrates the outstanding features of new blast-furnace charging equipment recently installed. The installations described are : the bucket system of charging at the plants of Baldwins Ltd., Bell Bros. Ltd., and Bengal Iron and Steel Co., Ltd., and the "vertical-horizontal" type of charger at the plant of the Redbourn Hill Iron and Coal Co., Ltd.

J. D. Knox, *Skip Tubs Replace Orē Burrows* (Iron Trade Review, May 7, 1925, vol. 76, pp. 1189-1193). The skip-charging apparatus recently put into operation at the Upson furnace of the Bourne-Fuller Co., Cleveland, Ohio, is described and illustrated.

The Champion Blast Meter (Iron and Coal Trades Review, Jan. 16,

1925, vol. 110, p. 96). The Campion blast meter, for registering blast-pressure in cupolas and furnaces, consists of a Pitot tube installed in the air main and connected to the pressure and volume indicator. The volume indicator is a gauge of the inclined tube type. It is calibrated to read directly in cubic feet of air delivered per hour. The pressure gauge of the mercury type is graduated in ounces per square inch and inches.

M. Paschke, *A Sand Dressing and Moulding Machine for Moulding Pig Beds* (Stahl und Eisen, Dec. 25, 1924, vol. 44, pp. 1771-1772). The author gives an illustrated description of a new machine for preparing the moulds on a pig bed, which was designed to overcome the troubles due to the adherence of sand to the pigs. In this it is claimed that the machine has proved a success and the pigs come out of the moulds with clean surfaces and sharply defined edges.

Blast-Furnace Practice.—H. G. Scott, *The Practical Management of Blast-Furnace Plants in Cleveland* (Proceedings of the Cleveland Institution of Engineers, Session 1924-25, No. 2, pp. 29-79). The author discusses some problems in the practical management of blast-furnaces in the Cleveland district. Water cooling, and soft and dirty coke, are among the subjects dealt with. A method of calculating a heat balance of the blast-furnace in terms of hundredweights of carbon per ton of pig iron is included in the paper.

E. H. Lewis, *Presidential Address* (Journal of the West of Scotland Iron and Steel Institute, Oct.-Nov. 1924, vol. 32, pp. 2-8). Some interesting particulars are included in this Address, of the valuation of coal for blast-furnaces, with special reference to Scottish practice.

R. H. Ledbetter, *Blast-Furnace Practice in the Birmingham District* (Paper read before the American Iron and Steel Institute, Oct. 1924). The striking economic feature of the Birmingham district of Alabama is the location of the iron ore deposits and coking coals on opposite sides of the valley, approximately six miles apart, with outcroppings of good dolomite, which fulfils all requirements for a fluxing stone. The iron ores used in the furnaces consist largely of hard red hæmatites, with a small percentage of soft red hæmatites and brown hæmatites or limonites. The Big Seam supplies most of the tonnage of the district, and the outcrop on Red Mountain shows workable thickness over an extent of about sixteen miles. The following are typical analyses of Big Seam Ore :

	Per Cent.	Per Cent.	Per Cent.
Iron	36·82	37·10	35·28
Silica	17·90	13·18	10·38
Alumina	3·03	3·05	3·12
Lime	13·67	16·02	19·35
Manganese	0·17	0·16	0·16
Phosphorus	0·37	0·36	0·30
Moisture	1·00	1·00	1·00

The coking coals of the district are limited to the Warrior Field. It is necessary to wash practically all the coals before coking. There are

in the district twenty-four blast-furnaces, with a total annual capacity of 2,735,000 gross tons of pig iron. The furnaces vary in size from the smallest of approximately 10,000 cubic feet in content to the largest of 31,235 cubic feet, the latter being the cubical content of the recently rebuilt No. 1 Ensley stack of the Tennessee Coal, Iron, and Railroad Company. On account of the low metallic content of the ore charged, the furnaces produce more than 2,300 lbs. of slag per gross ton of iron. This high slag volume is very destructive to the hearth linings, and as a result frequent outbreaks have occurred. However, in recent years these have been overcome by the use of stronger hearth jackets, better protected and cooled. At a number of furnaces the hearth well has been done away with. It is usual to protect the tuyere zone with cast iron or steel segments, and it is often necessary to maintain constant water cooling. A number of types of stock line protectors are also in service on account of the excessive abrasive action of the charge. Nine of the twenty-five furnaces are hand-filled, and are provided only with a single large bell without gas seal. Of the fifteen mechanically filled furnaces, thirteen are equipped either with the Brown or McKee type of top. Many types of stove are in use, the two-pass, the three-pass, and the four-pass all being in service. No gas-blowing engines are used in the district, the majority of the furnaces being blown with reciprocating engines, principally of the vertical long-head type. The steam for prime movers is generated almost exclusively by vertical water-tube boilers, using blast-furnace gas, supplemented by hand-firing of coal and at some plants by the use of coke-oven gas. A number of the furnaces are equipped with gas washers and dry cleaners. The flue dust production of the furnaces averages approximately 135 lb. per ton of iron. The low iron and high carbon content of the dust prohibits sintering by any of the present commercial systems. Fifteen furnaces produce foundry iron, eight produce basic iron, which is conveyed direct to open-hearth furnaces, and one furnace is usually operated on ferro-manganese, or special iron. There are no known ores in the district available in commercial quantities for the manufacture of Bessemer pig iron. A few years ago a method was developed for the manufacture of low phosphorus pig, by charging into the furnace scrap, coke, gravel, dolomite, and a small quantity of manganese ore, producing a very high grade of Bessemer iron. The furnaces in the district are operated by the following concerns: Tennessee Coal, Iron, and Railroad Co., twelve furnaces; Republic Iron and Steel Co., three furnaces; Sloss-Sheffield Steel and Iron Co., four furnaces, and the Woodward Iron Co., five furnaces. The record of the No. 3 Ensley furnace of the Tennessee Coal, Iron, and Railroad Co. for August 1924, showing an average production of 490 tons per day, is included in the paper.

H. E. Mussey, *Blast-Furnace Practice in Alabama* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1924). The developments in blast-furnace design and practice in the Birmingham district of Alabama is described.

G. Chaudron, *Investigation on the Reversible Reactions of Hydrogen and Carbon Monoxide on Iron Oxides* (Revue de Métallurgie, Aug. 1924, vol. 21, pp. 462-472). As far back as 1887 Debray showed that mixtures of hydrogen, water vapour, carbon monoxide, and carbon dioxide acted differently in contact with oxides according to the proportions in which these gases were present in the mixtures. A survey of investigations carried out on this subject, including those of Sainte Claire Deville, is given. Those bearing on the carbon oxides, which in their practical applications are of greater importance, and include the work of Bell, Baur, and Glassner, are described separately. The author's own researches are embodied in an equilibrium diagram of CO , CO_2 , H_2 , and H_2O , with Fe , FeO , and Fe_3O_4 . From this diagram it may be deduced, for example, that a mixture of equal volumes of hydrogen and water vapour will reduce Fe_2O_3 to the protoxide at temperatures above 700°C ., while a mixture of equal volume of CO and CO_2 will effect this reduction at temperatures above 600° . Pure protoxide is unstable below 570°C . The theoretical interest of the research arises from its indicating the method of preparing pure iron protoxide which, chemical text-books notwithstanding, has not been done hitherto. The pure magnetic oxide can also be prepared by making the conditions such as are required according to the Fe_3O_4 zone of the equilibrium diagram.

H. Kamura, *Reduction of Iron Ores by Carbon Monoxide* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). The author has investigated the proper temperature for the reduction of iron ores by carbon monoxide. The influence of ore size on the rate of reduction; the rate of reduction on different kinds of ore; and the maximum size of ore allowable for reduction in a certain time were also determined. The results of the investigation show that the proper temperature for the reduction of iron ore by carbon monoxide depends on the physical properties and the chemical composition of the ore. In the case of limonite or hæmatite, it is about 900°C .; in the case of magnetite or magnetite sands, slightly higher temperatures are needed. Generally the density of an ore will indicate its reducibility. The degree of crystallisation of an ore, also, has much influence on its reducibility. The rate of reduction is determined by reducibility, size of ore, and volume of carbon monoxide passed. In the experiments nearly perfect reduction was obtained in from two to three hours on ore 1 centimetre in size, using the proper volume of gas. The author is of the opinion that the present methods of steel manufacture may be replaced in the future by the direct process, in which the ore is reduced at low temperature and the resulting spongy iron refined in an electric furnace without cooling.

F. T. Sisco, *The Chemistry of Iron and Steel* (Transactions of the American Society for Steel Treating, Mar. 1925, vol. 7, pp. 363-378). The second of a series of four papers dealing with the chemistry of iron and steel. The chemistry of the blast-furnace process and the Bessemer process are dealt with in this paper.

T. T. Read, *Probable Error in Blast-Furnace Records and Calculations therefrom* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). According to the author, nearly every measuring operation for the purpose of securing blast-furnace records involves a possible error of 5 per cent. or more, and the quantities that are commonly measured with greater accuracy than this have to be multiplied or divided by figures involving a possible error of 5 or 10 per cent., thus introducing a corresponding error into the quotient. In interpreting curves or tabular summaries, the possible error should be always kept in mind, and observed differences should only be used with caution in drawing inferences and deductions as to the blast-furnace process.

It must not be inferred from the foregoing that since blast-furnace records show determinations made with only as high a degree of commercial accuracy as practical considerations of expense permit, and must be interpreted in the light of the probable errors involved, they are therefore not a valuable guide to blast-furnace operation.

J. Seigle, *Indices of the Actual and the Ideal Working of a Blast-Furnace* (Revue Universelle des Mines, Aug. 15, 1924, vol. 3, series 7, pp. 213-216). Formulæ are given bearing on the necessary relation between the carbon dioxide and carbon monoxide, in terms of a given blast-furnace charge, showing the modifications necessary in using Gruner's formula. The ratios of the actual yield to the ideal as propounded by Gruner, on the one hand, and to the actual yield per ton of coke, are quite different owing to the numerous factors which intervene to falsify the theoretical conditions obtaining.

E. C. Evans, *American Blast-Furnace Research, 1916-1924* (Fuel Economy Review, Feb. 1925, vol. 4, pp. 18-23). The results obtained by various investigators of the United States Bureau of Mines in their investigations of blast-furnace phenomena are summarised. A list of references to the original reports is included.

W. G. Imhoff and D. E. Ackerman, *Research Method for Blast-Furnaces* (Iron Age, Jan. 15, 1925, vol. 115, pp. 203-211). The authors have developed a series of symbols as an aid in studying blast-furnace operation. The symbols are classified under three main divisions, iron symbols, slag symbols, and symbols showing the condition of the blast-furnace. The practical operation of the system is described.

C. E. Macquigg, *The Trend in Metallurgy Last Year* (Iron Age, Jan. 1, 1925, vol. 115, pp. 61-64). A review of the developments in the production of iron and steel during 1924.

D. Perietzeano, *Tests on the Use of Mazout in the Blast-Furnace* (Revue de Métallurgie, Oct. 1924, vol. 24, pp. 624-627). An account is given of some experiments carried out for the Roumanian Government with a view to ascertaining the extent to which coke, which is very scarce in that country, can be superseded in blast-furnace practice by using cheaper fuels, such as residues from the petroleum industry. In recent

Swedish electrical blast-furnace practice, much of the heat energy required (up to 65 per cent. of that of the coke usually employed) has been supplied by electricity, the remaining coke being used only to supply the carbon oxides necessary for the reducing reactions, or, at any rate, such has been the theory underlying the process. It has been with the same objects that the Roumanian experiments have been conducted. The fuel which it is ultimately intended to use is low-grade pulverised coal, but the actual experimental work has been based on the use of mazout, as the conditions under which this could be burned at the tuyeres are sufficiently similar to those obtaining when pulverised fuel is used to render the results and the experience comparable. The blast-furnace selected for the experiments was a small, old-fashioned one some 40 feet in height, and ordinarily working on charcoal. The burden contained about 60 per cent. of Fe_2O_3 , and the air-blast was heated to from 300° to 400°C .; the mazout itself, which has an ignition point at 136°C ., being heated to between 80° and 100°C . The experiments cannot be said to have been conclusive, as only 12 per cent. of the charcoal usually employed was saved. Useful data are, however, derivable from the investigation, which shows, first and foremost, that a sprayed fuel can satisfactorily be employed in blast-furnace practice, and, secondly, the circumstances under which it can be made effective. In a larger and more modern furnace the results would probably prove more satisfactory from the fuel economy point of view. The pig iron made during the experiments was in every way equal to normal charcoal smelting practice.

D. Perietzeano, *Oil Fuel for Blast-Furnace Work* (Foundry Trade Journal, Feb. 12, 1925, vol. 31, p. 143). An abstract in English of the above paper.

G. M. Kirilloff, *Manufacture of Pig Iron by Means of Peat* (Messenger des Industries des Métaux Russe, Nos. 9–12, vol. 1, pp. 62–66; abstracted in the Revue de Métallurgie, Dec. 1924, vol. 21, pp. 570–571). An account of experiments carried out at the Koulebak Works in Russia during July 1923 on the smelting of iron in a blast-furnace by means of peat. The charge consisted of dirty scrap (25 per cent. impurities) with some 10 per cent. of iron ore and mill cinder. The peat was air-dried and contained 25 per cent. of moisture and 2 to 3 per cent. of ash, the weight of a cubic metre being about 300 to 335 kilogrammes. The average consumption per ton of pig was 2.4 tons, and the average daily production of pig iron, which was of grey forge type, was 35 tons. The waste gases contained 8 per cent. of CO_2 , 25 per cent. of CO , and 14 per cent. of H_2 , the CH_4 not having been estimated. Its calorific value was 1464 calories as against the 950 to 1000 calories in a normal blast-furnace gas. A heat balance is given. The process is said to be economically sound, seeing that the peat is coked in the blast-furnace itself, and the gases go to enrich the ordinary gas. This type of operation resembles gas-producer practice in a slagging producer (as the ashes fuse) with a rich yield of gas, and pig iron, as a by-product. The by-products of the gases are, moreover, easily recoverable, and the

ammonia yield considerable; but the tar is of an inferior nature to that obtained when coal is used.

R. v. Seth, *The Occurrence of Vanadium in Iron Ores, its Influence on the Smelting Process, and the Possibility of its Recovery* (Jernkontorets Annaler, 1924, vol. 79, pp. 561-583).

Enriched Blast.—*Use of Oxygenated Air in Metallurgical Operations* (Abstracts of papers forming the Symposium on Oxygenated Air read before the American Institute of Mining and Metallurgical Engineers, Feb. 1924). A summary is given of a report of a committee appointed by the United States Bureau of Mines to inquire into the use of oxygen or oxygenated air in metallurgy and allied processes. The following papers are also included:

Enriched Air in Metallurgy, by W. S. Landis.

Application of Oxygen-enriched Air to the Blast-Furnace, by T. L. Joseph.

Use of Oxygenated Air in the Blast-Furnace, by A. G. McKee.

Use of Oxygenated Air in the Iron Blast-Furnace, by C. Hunt.

Proposed Use of Oxygen in the Open-Hearth Furnace, by S. Cornell.

Use of Oxygen in the Gasification of Coal, by W. Dyrssen.

Cheap Oxygen in Metallurgy, by E. B. Kirby.

Calculated Thermal Effects of Use of Oxygenated Air, by C. S. Witherell.

Effect of Oxygen-enriched Air in Roasting Zinc Ores, by B. M. O'Harra, W. Kahlbaum, E. S. Wheeler, and W. J. Darby.

M. Steffes, *The Commercial Production of Oxygen by the Decomposition of Atmospheric Air, at the Terre-Rouges Works, Belval* (Revue de Métallurgie, Dec. 1924, vol. 21, pp. 707-728). A description of an installation for the production of 50 cubic metres of oxygen per hour, at the Esch works of the Terres Rouge Company (Société Métallurgique). The two leading industrial processes and the plant required in each are discussed. These are the Linde process and the Claude process. In both processes air is, in the first instance, liquefied. The subsequent decomposition of the liquid air into oxygen and nitrogen differs in the two processes. That employed at Esch is a modified combination of both.

Blast-Furnace Stoves.—A. Cousin, *Progress Realised in the Construction and Working of Cowper Stoves* (Revue Universelle des Mines, Oct. 1, 1924, vol. 4, Series 7, pp. 6-16). In a blast-furnace plant producing 1000 tons of pig iron per 24 hours, a reduction of 40 per cent. of the resulting gases used in the Cowper stoves to 20 per cent. would render available for other purposes no less than 850,000 cubic metres of gas. This is, as fuel, equal to the combustion of 105 tons of coal, and can be used for mill furnaces, etc., and the surplus for generating electricity. To achieve such a reduction in gas consumption in the Cowper stoves, however, certain modifications are necessary. Forced draught must

be used, and the chequer work must be modernised by making the air channels in brickwork smaller than those habitually used. Thin-walled chequer bricks, preferably of circular section, should, moreover, be used as the heat exchanges become more efficient. Smaller blast-channels presuppose, however, good cleaning of the gas, or the dust will soon choke them, besides injuring the thin-walled refractory brickwork by scorification. The practice at the Cockerill works at Liège in this respect is described and illustrated.

M. Tigerschiöld, *Improvements in the Construction of Stoves for Swedish Charcoal Furnaces* (Jernkontorets Annaler, 1925, vol. 79, pp. 1-38).

A. Hallback, *Stoves for Blast-Furnaces* (Jernkontorets Annaler, 1925, vol. 79, pp. 55-90). Improvements in the design of apparatus for preheating the blast of Swedish blast-furnaces are discussed.

Cleaning of Blast-Furnace Gas.—A. E. Rowe, *The Cleaning of Blast-Furnace Gas* (Proceedings of the Cleveland Institution of Engineers, Session 1924-1925, No. 4, pp. 127-174). The author discusses the savings effected in the use of clean gas. Heat-balance diagrams are given showing the consumption of B.Th.U. when using clean gas and dirty gas. The improved conditions obtained by the use of clean gas in conjunction with the Pfoser-Strack-Stumm system of heating stoves and improved burners on boilers are also shown. When using dirty gas the losses amount to 51 per cent. of the B.Th.U. in the gas, with clean gas the losses amount to 32 per cent., and with clean gas in conjunction with the Pfoser-Strack-Stumm system the losses are 26 per cent. The wet and dry methods of gas cleaning are compared and the P.-S.-S. system of heating stoves is outlined.

E. Lavandier and M. Gangler, *Influence of the Method of Cleaning on the Value of Blast-Furnace Gas* (Revue de Métallurgie, Sept. 1924, vol. 21, pp. 501-512). After an introduction by E. Damour (*ibid.*, pp. 499-500), who points out that in some instances a blast-furnace uses only 44 per cent. of the calories in the coke charged in the necessary reductions in the furnace, the remaining 56 per cent. escaping with the waste gases, the authors remark that wet cleaning, being accompanied by a loss in the sensible heat of the gases would appear to be an unfavourable condition. In dry cleaning the saving of such heat is claimed as an advantage. Careful examination of the question reveals, however, the importance attaching to the presence of water vapour in wet-cleaned gas, which is of a nature to redress the supposed disadvantage. By means of a series of tables, diagrams, and calculations, the effect of this water-vapour in wet-cleaned gases is shown. In gas-fired metal mixers such gas shows a marked superiority over dry-cleaned gas, and the same applies to its use in the hot-blast stoves. For use in gas engines the gas requires further cooling, and its efficiency for this purpose bears a ratio to the amount of cooling it has undergone. Combustion temperature is not the predominant factor in many cases; the yield or efficiency

is more important, and this is a function of the amount of heat transferred and used in any given appliance. The quantity of heat rendered available in a furnace is influenced by the combustion temperature, the weight of the resulting gases and their outgoing temperature. The heat potential of gas cleaned by wet processes, and cooled, therefore, in the process, is far higher than that of a gas issuing with the throat temperature of the furnace (110 to 130° C.). The moisture content of a gas being a function of its temperature, a water-cooled gas, even although saturated, contains less moisture than hot gas, and the point involved is that the drier the gas, the higher its combustion temperature. This factor may be a decisive one in cases where the prime condition sought is high temperature.

G. Barrière, *Electric Cleaning of Blast-Furnace Gas* (Revue de Métallurgie, Jan. 1925, vol. 22, pp. 21-38). The system of cleaning the waste gases by electricity at the blast-furnaces of the Firminy Company is described. The gas passes through a nest of vertical tubes, through each of which passes a nickel chromium high-tension electrode. The tubes are about 8 feet 3 inches long and 8 inches in diameter, and with a negative voltage of 32,000 to 40,000, about 90 per cent. of the dust is precipitated, the energy consumed being 0.8 kilowatt per cubic metre of gas per second.

The Elga Electrical Precipitation Gas-Cleaning Plant (Iron and Coal Trades Review, March 27, 1925, vol. 110, p. 506). The general arrangement of the Elga system is described, and particulars of operating results are given.

R. P. Hudson, *Tests Dust Catcher Efficiency* (Iron Trade Review, Mar. 26, 1925, vol. 76, pp. 820-821). A method is described for determining the amount of dust in blast-furnace gas.

P. Drinker and R. M. Thomson, *Determination of Suspensoids by Alternating Current Precipitators* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). The constructional details and adaptation of portable alternating current precipitators to the quantitative determination of suspensoids, such as dusts, fumes, and smokes, are discussed. The distinction between the alternating-current method, using glass collecting electrodes, and the rectified current method, using metal collecting electrodes (Cottrell process), is brought out.

F. G. Cutler, *Reduction of Fuel Wastes in the Steel Industry* (Transactions of the American Society of Mechanical Engineers, 1922, vol. 44, pp. 167-188). The quantity of gas to be expected in the production of one ton of pig iron is computed, and the uses to which this gas may be put are analysed quantitatively. It is shown that the total heat from the fuel by-products of a ton of pig-iron is more than sufficient to finish a ton of steel.

M. Steffes, *Tests on the Regulation of Blast-Furnace Gas-Consuming Appliances: Stoves, Gas-Engines, and Boilers* (Chaleur et Industrie, Jan. 1925, pp. 3-10). Emphasises the need for economy in the

use of blast-furnace gas for various heating purposes in and about works. Tables and diagrams derived from actual practice at the Belval Works of the Terres Rouges Company are given, showing the greater efficiency derived from correct throttling of all gas-consuming appliances, and the economy due to preventing leakage. Far better results can be obtained when due regard is paid to the methods of regulating the supply in accordance with the exact needs of such stoves, gas-engines, and boilers, than when this regulation is left to rule-of-thumb and haphazard devices.

Electric Smelting of Iron Ore.—Professor J. A. Leffler, *Electric Pig Iron Manufacture in Sweden* (Lecture before the Swedish Engineers' Society: Iron and Coal Trades Review, Mar. 27, 1925, vol. 110, pp. 510-511). The author describes electric smelting practice in Sweden, and gives particulars of the plants in operation at Hagfors, Domnarfvet, Söderfors, Trollhättan, and Porjus. The economical carrying out of electric pig iron production is largely dependent on the percentage of iron in the ore, and on the other constituents, as well as on their physical nature. An ore with a high percentage of iron and of such composition that it forms a good slag, is the most suitable for the process, provided that it is in lumps without dust. The volumetric proportion between reducing agent and ore is much less than in a blast-furnace, and the physical condition of the ore, therefore, is of more consequence for helping the passage of the gases up the shaft. In certain cases it has been possible to use up to 20 to 30 per cent. of dusty ore, but it depends very much on the condition of the reducing agent, whether, and how much, fine ore can be used. In the Elektrometall type of shaft furnace charcoal is used exclusively as fuel. In Sweden carbon electrodes are used either of Swedish make or imported from Germany or the United States. The following table gives some typical analyses of pig iron made in a modern Swedish shaft furnace :

	Carbon per Cent.	Silicon per Cent.	Man- ganese per Cent.	Sulphur per Cent.	Phos- phorus per Cent.
Acid Bessemer . . .	...	1-1.5	3-3.5	0.008	0.016
Basic „ . . .	...	about 0.50	0.60	0.010	2.000
Open-hearth . . .	3-3.5	0.65	0.31	0.018	0.015
„ „ . . .	3.65	0.33	0.39	0.010	0.016
Lancashire . . .	...	0.28	0.31	0.018	0.016
„ „ . . .	2.88	0.41	0.22	0.018	0.042

About 600 cubic metres (21,100 cubic feet) of gas are obtained per metric ton of pig iron, or only about one-seventh of the quantity obtained in a blast-furnace. It contains volumetrically on an average 15 to 30 per cent. of CO₂; 55 to 70 per cent. of CO; 8 to 12 per cent. H; 0.5 to

2 per cent. CH_4 ; and 0.5 to 2 per cent. N. The calorific value of the gas in dry condition is 1900 to 2600 calories per cubic metre. An essential principle of the Elektrometall shaft furnace is that protection must be arranged for those parts of the furnace lining which are exposed to destruction by heat, by blowing cool furnace gas into the hearth. This is arranged in such a way that a certain quantity of gas is drawn off at the top of the furnace, passed through pipes, and introduced into the smelting chamber by means of tuyeres. This circulation has the effect of conveying heat from the smelting chamber up the shaft, where it serves to preheat the charge. The excess gas escaping from the furnace has been used in several ways. Where open-hearth furnaces exist, it has proved to be an excellent fuel for them, but it can also be used for the heating of ladles, soaking pits, &c. It has been used with success for the calcining of dolomite in kilns. The arcs between the electrodes and the charge are the main source of heat, and here probably a temperature of about $3000\text{--}3500^\circ\text{C}$. prevails. This temperature, however, decreases rapidly in all directions, because the fields between the electrodes are being cooled by the circulation of gas. But the high temperature at and below the electrodes converts these zones into proper reaction hearths, where a direct reduction of ore, carbonising of iron, and smelting of iron and slag actively takes place, while CO is produced. On the bottom of the hearth a temperature prevails amply sufficient for keeping the pig iron and the slag liquid. The direct reduction of the ore, however, is very endothermic, and the gas circulation assists in the lowering of the temperature. Therefore it is necessary to avoid making the hearth too deep, in order to avoid the "freezing" of the iron and other working difficulties. Some of the factors which influence the cost of the production of pig iron by this process are discussed.

G. Tysland, *Experimental Work on the Electric Smelting of Iron Ore* (Teknisk Ukeblad, 1924, vol. 71, pp. 239-247). The author describes experiments with the Elektrometall furnace, using coke as a reducing agent. The experiments were carried out under the auspices of the Norwegian Government. Various types of native ore were used. On the basis of the experiments it is calculated that pig iron can be produced with a consumption of 2700 kilowatt-hours, 380 kilogrammes of coke, and 8 to 10 kilogrammes of electrodes per ton of iron.

Manufacture of Ferro-Alloys.—J. A. Barr, *Manufacture of Ferrophosphorus at Rockdale, Tennessee* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1924). Particulars are given of blast-furnace practice for the manufacture of ferrophosphorus at Rockdale. The furnace has the following dimensions: Height, 40 feet; inside hearth diameter, 8 feet; bosh diameter, 12 feet; bosh angle, 80° . The hearth and bosh are water-cooled, as the molten charge is very corrosive and would soon cut its way through an uncooled jacket and lining. The furnace is equipped with six water-cooled

tuyeres. The furnace gases pass at about 450° to 500° F. into a brick-lined downcomer through two dust-catchers into a gas washer; the flue-dust is wasted. A battery of four single-pass stoves uses part of the gas to heat the blast to about 1000° F., the remainder of the gas is burned under boilers. Blast is supplied at 12 to 15 lbs. pressure. The usual operating procedure is to add five regular charges, consisting of phosphate rock, iron ore, or mill cinder, high-silica tailing, and shot ferro-phosphorus. The amount of coke used is about twice that required in pig iron practice. Every fifth time a regular pig iron charge of iron ore, limestone, and coke is added to keep the furnace working freely. Sometimes a coke charge is added in addition, according to the needs of the furnace. The ferro-phosphorus is tapped every six hours and run on to a cast-iron floor, where it cools in thin slabs and can be easily broken and handled. Slag is tapped every 3 hours into a granulating pit and subsequently passed over a magnetic separator for the recovery of shot ferro-phosphorus. The capacity of the furnace is about 35 tons of shot per 24 hours. A typical analysis of ferro-phosphorus is as follows :

	Per Cent.
Phosphorus	18.0 to 22.0
Iron	80.0 to 76.0
Oxygen	0.2
Sulphur	0.3
Silicon	0.1
Carbon	0.1
Manganese	0.2

The blast-furnace reactions are shown diagrammatically.

T. Swan, *Production of Ferro-Phosphorus in the Electric Furnace* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1924). In the manufacture of ferro-phosphorus the blast-furnace can only economically produce a grade of product up to about 20 per cent. The alloy, with a high percentage of phosphorus, can be made only in the electric furnace. In the ordinary operation of the electric furnace an alloy may be produced containing 26 per cent. phosphorus; this is the limit, for it does not seem possible to produce a higher phosphorus-alloy even if large excesses of phosphatic material are used. The raw materials used consist of phosphate rock, coke, silica, and iron scrap. The phosphate rock may be of the high grade commonly used in the manufacture of fertiliser, although a material containing higher percentages of silica than may be used in fertiliser manufacture has been found satisfactory. The excess of silica is not objectionable, because it combines with the lime in the phosphate rock and is withdrawn with the slag. Iron borings or turnings are ordinarily used, but it is possible to use iron ore instead. When ore is substituted additional coke and power are necessary, but this is largely compensated for by the fact that the source of iron is less expensive. Pyrites cinder and mill cinder can also be used. The metal and slag are tapped together into a large iron chill in which the metal remains, the slag over-

flows into a bed of sand. The ferro-phosphorus after cooling is broken up for easy handling. In the production of high-grade ferro a large excess of phosphorus must be charged, and the losses by volatilisation become very large. For this reason a closed furnace is used, which permits drawing off the vapours through a gas main. By admitting air and moisture into these vapours, phosphorus pentoxide and then orthophosphoric acid are formed. The orthophosphoric acid is collected by condensation and electric precipitation by the Cottrell system. In the production of low-grade material a closed furnace is not necessary and a rectangular smelting furnace is used. The electric furnace operates at about a 94 per cent. power factor, and a 90 per cent. load factor may be procured. The average electrode consumption may be kept at 5 lbs. per 1000 kilowatt-hours input. Electric furnace ferro-phosphorus is marketed in two grades, analyses of which are as follows :

	Per Cent.	Per Cent.
Phosphorus	18.00	24.00
Silicon	0.50	0.75
Sulphur	0.005	0.005
Carbon	0.25	0.25
Iron	80.00	74.00
Miscellaneous	1.245	0.995

T. H. Gant, *Cobalt : Its Production and Some of its Uses* (Paper read before Birmingham Section of Institute of Metals, Jan. 6, 1925). The ores cobalt are enumerated and analyses of the Canadian and Australian cobalt ores are given, with some notes on the smelting of the ores. For use in the iron and steel industry ferro-cobalt is prepared containing 10 to 15 per cent. of iron and 80 to 90 per cent. of cobalt. The equilibrium diagram of cobalt and iron, plotted by Ruer and Kaneko, shows that the two metals form a series of solid solutions. The use of cobalt as an alloy in magnet steel is referred to at length, particulars being given of the treatment and magnetic properties of such steels. A short summary of previous investigations on the electro-plating of iron and other metals with cobalt is also given.

A. P. Child, *An Electric Furnace for Making Ferro-Vanadium* (Iron Age, Mar. 5, 1924, vol. 115, p. 696). Brief particulars are given of an 80-ton electric furnace in operation at the plant of the Vanadium Corporation of America, Bridgeville, Pa., U.S.A.

N. Parravano and A. Scortecchi, *Nitrogen in Iron Alloys* (Annali di Chimica Applicata, 1924, vol. 14, pp. 289-291). Ferro-alloys such as ferro-manganese, ferro-chromium, ferro-vanadium, ferro-titanium, and silico-calcium, when melted, usually give off a proportion of the gas contained in the alloy, but in ferro-manganese and ferro-chromium a slight increase in the total gas has been noted. In ferro-vanadium the gaseous and combined nitrogen is distinctly lowered by melting, but in ferro-manganese the total nitrogen remains unchanged. In the other alloys the proportion of combined nitrogen increases five- to nine-fold on melting.

R. J. Anderson and Laura D. Anderson, *The Ferro-Alloy Industry in 1924* (Iron Age, Jan. 1, 1925, vol. 115, pp. 65-68). The authors review the developments in the production and uses of ferro-alloys during the past year.

Iron Industries of Various Countries.—F. W. Harbord and E. F. Law, *British Iron and Steel Industry* (Revue de Métallurgie, Dec. 1924, vol. 21, pp. 572-574). A translation, in abstract, into French, of the paper read before the Empire Mining and Metallurgical Congress, at Wembley, in June 1924, and since published in the "Proceedings" of that Congress, Part IV., pp. 181-198. The paper by Sir W. J. Larke and M. S. Birkett, read at the same Congress, *Some Economic Considerations affecting the Iron and Steel Industry*, has also been translated in full (Revue de Métallurgie, Sep. 1924, vol. 21, pp. 199-215).

German Iron and Steel Capacity (Deutsche Bergwerks Zeitung : Iron and Coal Trades Review, Feb. 27, 1925, vol. 110, pp. 349). A table is given showing the pig iron, steel, and puddled iron capacity of sixteen leading concerns in Germany, and the percentages they represent of the total output of the whole country. The same information is also given with regard to plant in Rhenish Westphalia, excluding the Siegerland, the Wetzlar, and the Saar Districts.

A. B. Sloane, *The Iron Industry of Sweden* (Blast-Furnace and Steel Plant, Apr. 1925, vol. 13, pp. 173-176). A short account is given of the present position and development of the Swedish iron industry.

The Collective Mining and Iron Exhibit at the Jubilee Exhibition, Gothenburg, in 1923 (Jernkontorets Annaler, 1924, vol. 79, pp. 601-757). Illustrated descriptions are given of the numerous exhibits of iron and steel products, illustrative of the Swedish iron industry.

The Russian Metallurgical Industries (Engineering, Apr. 10, 1925, vol. 119, pp. 461-462). A short review is presented of the present condition of the Russian iron and steel industries, with a comparison of the position in 1913. The output of pig iron, which was 4,110,000 tons in 1913, amounted to 640,000 tons for the twelve months ending September 1924. The production of steel was 4,210,000 tons in 1913, and 972,000 tons in 1924. The 1924 figures, however, show a considerable increase over those for 1923.

A. W. G. Wilson, *Development of Chemical, Metallurgical, and Allied Industries in Canada* (Canada, Department of Mines, Mines Branch, 1924, Report No. 597). This report has been prepared to aid in the development of new industries in Canada by presenting in concise form general statements showing existing conditions in the fields of metallurgical or chemical manufacturing. The present position in a number of other industries in Canada which utilise mineral or chemical products has also been reviewed.

Natal Iron Industry (Engineer, Nov. 21, 1924, vol. 138, p. 594). The Newcastle Ironworks in Natal Province have been equipped with a modern blast-furnace, and the works are in a condition to produce pig

iron at the rate of 150 tons per day. Owing to lack of capital, however, the company has not been able to begin operations, though on account of the high price of imported pig iron there would be a great market for iron manufactured locally. The Government has agreed to pay a bounty of 15s. a ton to the company, provided they use local ore and that not less than 50,000 tons of pig iron per year are produced.

G. J. Young, *Making Pig Iron from Utah Ore* (Engineering and Mining Journal-Press, Jan. 6, 31, 1925, vol. 119, pp. 209-210). Brief illustrated particulars are given of the blast-furnace plant of the Columbian Steel Corporation at Provo, Utah.

New Capacity in Iron and Steel Plants (Iron Age, Jan. 1, 1925, vol. 115, pp. 81-88). Particulars are given of new blast-furnace, open-hearth and electric furnace, and rolling-mill construction in the United States during 1924.

K. Thomas and J. E. Kelly, *A Brief Review of Iron Mining in Mexico* (Engineering and Mining Journal-Press, Dec. 20, 1924, vol. 118, pp. 976-977). The authors review the developments of the Mexican iron industry. The industry began about 1804 with the erection of a furnace at Coalmocan. This furnace was destroyed a few years later. Since that time iron has been produced in a number of districts, but at the present time its manufacture is being carried on by only two concerns. The chief iron-producing company is the Monterey Iron and Steel Co., which owns iron deposits in the Cerro del Mercado district in Durango, the Cinco de Mayo iron mines in Coahuila, and a 300-ton blast-furnace at Monterey. The Mexican Government recently appointed a commission to study the iron and steel situation. The commission in a preliminary report recommended a duty on all iron and steel shapes, and, later, on machinery when the Mexican industry shall be sufficiently developed. Preferential railway rates for domestic producers were also recommended. The report recognised the need of foreign capital and management in the development of the industry, and such foreign-owned mines and furnaces are to enjoy the proposed preferential treatment.

Pig Iron Prices.—J. W. Reichert, *Pig Iron Prices at Home and Abroad since 1910* (Stahl und Eisen, Mar. 12, 1925, vol. 45, pp. 369-372). The yearly average prices of the principal kinds of foundry pig iron manufactured in different countries are compared. For the United Kingdom, Germany, and the United States, the comparison goes back to 1900, and for France and Belgium to 1920.

History of Iron.—J. P. Bedson, *John Wilkinson, "Father" of the British Iron Trade* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Oct. 30, 1924, vol. 30, pp. 382-384). The paper contains some interesting particulars of the life and work of John Wilkinson, 1728-1800, builder of the first iron boat and inventor of the cupola furnace. He was also an active promoter in the erection at Coalbrookdale of the first iron bridge.

H. Louis, *The History of Iron Manufacture* (Paper read before the Sheffield Society of Engineers and Metallurgists, Dec. 10, 1924).

G. E. Thackray, *Notes on the History of Iron and Steel* (Transactions of the American Society for Steel Treating, Oct. 1924, vol. 6. pp. 443-490). This paper, compiled from various sources, sets forth some of the salient points of the history of the manufacture of iron and steel.

II.—BLAST-FURNACE SLAGS.

R. S. McCaffery, *The Constitution of Iron Blast-Furnace Slags* (Paper read before the American Iron and Steel Institute, Oct. 1924). There are seventeen compounds of silica, alumina, lime, and magnesia that enter into the composition of blast-furnace slags, in addition to the ultimate constituents themselves. A list is given of these twenty-one components. These components form solutions of only two types. One, and by far the commonest type in slags, is like the solution formed by metallic lead and tin, with a eutectic at some intermediate composition, and the other type is like the solution of gold and silver, which forms an isomorphous series. The equilateral tetrahedron model is used by the author to represent the four-component system— CaO , MgO , Al_2O_3 , SiO_2 . The complete model shows the spaces of composition of primary crystallisation, and from the location of the interior tetrahedra faces the approximate mineral composition of a slag of any composition can be determined. Several interesting points brought out by a study of the model are discussed, and a table is included giving analyses of typical blast-furnace slags.

R. Grün, *Influence of Manganese on the Hydraulic Properties of Blast-Furnace Slags* (Stahl und Eisen, Nov. 6, 1924, vol. 44, pp. 1405-1409). The author has investigated to what extent the presence of manganous oxide affects the hardening capacity of slag cement, and his conclusions show that slags containing manganese lose in hydraulicity, and conversely by the elimination of manganese the hydraulic properties of a slag are improved. Silicates and aluminates, which enter largely into the composition of blast-furnace slag, are compared in a manganese free state and when containing manganese, and both these compounds deteriorate if manganese is present, but the aluminates not so much as the silicates.

R. Grün, *The Effect of Sulphides on the Properties of Blast-Furnace Slag and Slag Cements* (Stahl und Eisen, Mar. 5, 1925, vol. 45, pp. 344-346). The chief source of the sulphur in the slag is the coke, but where pyrites residues are smelted, these contribute a further proportion of sulphur to the slag. The results of a number of tests show that a content of CaS up to 16 per cent. has no deleterious effect on the strength properties, but appears to exercise a beneficial influence. Such slags set in a remarkably short time.

B. Kalling, *Influence of Alumina and Magnesia on the Chemical Properties of Silicate Slags* (Jernkontorets Annaler, 1924, vol. 78, pp. 283-307 : Stahl und Eisen, Mar. 5, 1925, vol. 45, pp. 246-348).

C. E. Ireland, *The Manufacture of Slag Brick and other Slag Products* (Paper read before the American Iron and Steel Institute, Oct. 24, 1924). The author describes the developments in the use of blast-furnace slag for the production of bricks and as an aggregate in concrete products in the Birmingham district of Alabama. Instead of the usual slag heaps a pouring pit system is used. Under this system four pits, 1000 feet long, 50 feet wide, and 15 feet deep are located near the furnaces. The pits are excavated by electric shovels and the slag transported to the crushing plant. After crushing the slag is passed over magnetic pulleys to recover any iron. A brick-making plant is in operation with a capacity of 30,000 bricks per day. The methods of brick manufacture are outlined.

H. Lossier, *Special Cements and the Future of Reinforced Concrete* (Bulletin de la Société d'Encouragement, Nov. 1924, vol. 136, pp. 738-754). Deals with the setting rates of a number of cements, as compared with that of ordinary Portland cement, which has the disadvantage of taking about thirty days properly to harden. An aluminate cement having the following composition, and setting hard in from four to eight hours, is recommended for reinforced structures :

	Per Cent.
Silica	10
Alumina	40
Iron and iron oxides	10
Lime	40

It is made by the intimate admixture of lime and bauxite, or aluminium silicate. Such cements successfully resist the action of many somewhat corrosive agencies.

III.—DIRECT PROCESSES.

Direct Production of Iron.—C. E. Williams, E. P. Barrett, and B. M. Larsen, *Sponge Iron Produced in Kilns* (United States Bureau of Mines : Iron Trade Review, Jan. 29, 1925, vol. 76, pp. 344-347). The authors describe both small-scale and large-scale experiments on the production of sponge iron. The small-scale experiments, which were carried out in muffles, show that the permissible temperature range for the reduction of iron ores without fusion, using solid carbon as a reducing agent, is about 875° to 1025° C., the most desirable temperature being about 950° C. The heat conductivity of finely divided iron-coal mixtures is low. Also, the reduction reactions in such charges are highly endothermic, so that a large heat input is necessary. These conditions make

rapid heating of the charge almost the first essential factor in the design of a furnace of high producing capacity. The experiments demonstrated that the muffle furnace is less practical than the direct-heated type for the reduction of iron ores on a large scale. The large-scale experiments were carried out in continuous rotary gas-fired kilns. The kilns were built with sections of different diameters. The charge of ground ore and coal enters the upper end of the kiln and passes rapidly in a thin layer through the preheating section. During the preheating period of 15 to 20 minutes, the volatile matter of the coal and the moisture in the the charge are driven off, and the charge enters the enlarged section at approximately 900° C. with 3 to 5 per cent. of the iron reduced. In this section the charge is in a layer of 13 to 15 inches deep. Maintained at a nearly constant temperature of 900 to 1000° C., the charge remains in this section for about one hour, during which period the reduction of the iron oxide is complete. The reduced product is discharged continuously through a pipe into a cooling chamber below the furnace. The cooled product contains a large quantity of excess carbon and coal ash which is removed by means of a magnetic separator. The concentrate usually contains less than 1 per cent. of carbon and 65 to 90 per cent. of iron, varying with the grade of ore treated. The experiments indicate that the rotary kiln gives consistently good results. For the problem of supplying sponge iron for chemical uses this furnace offers a satisfactory solution. Its importance in the problem of direct steel production will be largely dependent upon future developments.

E. P. Barrett, *A Brief Summary of the Development of the Sponge Iron Process* (Bulletin of the Canadian Institute of Mining and Metallurgy, Jan. 1925, pp. 60-68). The author reviews briefly the methods developed for the production of iron sponge and outlines the investigations conducted by the United States Bureau of Mines.

The Reduction of Iron Ore at a Low Temperature (Écho des Mines et de la Métallurgie, Oct. 1, Dec. 1, 1924, pp. 424-425, 520-521). Describes the Hornsey process, said to have been experimented upon at works in Chesterfield. It is a direct-reduction process requiring neither coke nor limestone, and the product is a sintered product comparable with malleable pig iron and easily convertible into either wrought iron or steel. The product contains about 98 per cent. of iron. The plant in which the process is conducted consists of three rotary retorts, in the upper of which the ore is heated to 800° C. by the surplus gas from the second retort, into which the heated ore falls by gravity and is mixed with low-grade coal, etc., by which it is reduced. The reduced product is delivered into the third retort and cooled to a temperature at which further reoxidation ceases. The carbon, which is low (0.01 to 0.04 per cent.) can be increased by altering the temperature of the reduction phase. Details of the power consumption and analyses of the ores and product, and a statement of the costs, are given. It is estimated that the pure iron product can be marketed at about 65s. as against 88s. a ton for a good grade pig iron made in the blast-furnace.

Electrolytic Production of Iron.—T. W. S. Hutchins, *Electrolytic Iron* (World Power, 1924, vol. 2, pp. 341–347). The author describes French, American, and British practice in the production of electrolytic iron, with notes on the mechanical and electrical properties of the product.

F. N. Budgen, *Electrolytic Iron* (Engineering Production, Apr. 1925, vol. 8, p. 98). Brief notes are given of the manufacture, properties, and uses of electrolytic iron.

R. Audubert, *The Structure of Electro-Chemical Deposits* (Revue de Métallurgie, Oct. 1924, vol. 21, pp. 567–584). The technology of the electro-deposition of metals is greatly affected by the conditions under which it is carried out, and still remains somewhat empirical. It is possible, however, from current practice and from the scattered literature of the subject to ascertain the principal factors which influence the nature of the deposit and its structure. The latter falls into three groups, according as it is (1) symmetrical, (2) homogeneous (columnar and fibrous), and (3) powdery. In the latter group the crystal elements vary in size and lack cohesion. There is also a fourth group, in which the deposits are spongy, due to the occlusion of hydrogen. The action of hydrogen can be controlled by the addition of certain elements in the bath. Iron has a marked tendency to be deposited in fine grains. The factors which have to be taken into consideration are: (1) The nature of the electrolyte, and whether it be the solution of a simple salt, or of mixed salts. (2) The effect of colloids which may be added to improve the deposit. Organic colloids have more influence than inorganic colloids. Their behaviour probably involves adsorption phenomena. (3) The presence of foreign matters, other than added colloids. (4) The current density. (5) Temperature. (6) Agitation of the electrolyte. (7) The nature of the surface upon which deposition takes place. Not only do all these factors act individually, but their influence on one another is considerable.

Swedish Charcoal Iron.—N. Danielsen, *Swedish Charcoal Iron* (Mining and Metallurgy, Dec. 1924, pp. 569–572). The author outlines the manufacture and properties of Swedish charcoal iron. The foundation for the process is high-grade iron ore and charcoal, from which a very pure iron is made in small blast-furnaces. A representative analysis of pig iron for making finished bar iron is:

	Per Cent.
Carbon (about)	4.0
Manganese	0.15
Silicon	0.35–0.50
Phosphorus	0.070
Sulphur	0.015

In pig iron used for the production of melting bars, the phosphorus content is lower than 0.025 and the manganese is higher.

The pig iron is brought into a small hearth, which is charged with 300 to 400 lbs. of pig iron preheated on the flue. A certain quantity of

slag left from a previous operation is present. Hot blast blown into the hearth brings the necessary quantity of oxygen for burning the charcoal in the hearth. On melting, the pig iron drops through the flame produced by the blast. The main part of the silicon and manganese of the pig iron is here reduced, raising the temperature of the batch, forming an oxidising slag rich with iron. As soon as the batch has gathered at the bottom of the hearth it is broken up with a pinchbar. This is the most important part of the whole operation, as the quality of the iron will be greatly dependent upon the skill and accuracy exercised by the smith. If the batch during this period is allowed to rest in contact with the charcoal without being covered by slag, the result will be local hard spots in the mild iron.

After 45 to 60 minutes the work at the hearth is completed, and the batch is brought to a hammer, where it is cleared of any eventual defects on the surface, squeezed in order to reduce the slag content, and finally shaped to a muck-bar about 7 inches square. This is cut into pieces generally weighing about 90 lbs., and rolled down without reheating to $3\frac{1}{2}$ inch or 4 inch square billets. These are then reheated and rolled to finished sizes of bars and wire rods.

The main object of the melting bars is to provide a metal low in manganese, silicon, phosphorus, and sulphur. Generally a guarantee is given of P max. 0.020 per cent. and S max. 0.010 per cent. The average carbon has, of course, to be low, but if local small spots should show up to 0.20 per cent. C, or even higher, this is of little importance in a melting bar. In finished bar iron and wire rods this must not be allowed. Thus, in order to facilitate a thorough reduction of carbon in the batch and to prevent the batch from being recarburised by the charcoal in the hearth, the slag is kept in liquid form by help of a certain amount of phosphorus. This is the reason why the most prominent makers of Swedish charcoal iron (except makers of muck-bars) run their analysis in phosphorus as high as 0.050 to 0.070.

Good charcoal iron for finished bars should contain less than 1.25 per cent. of slag. In rough bars often a somewhat higher amount of slag is found. The following analyses ought to be considered as representative for :

	Finished Iron.	Melting Bars.
Carbon	0.02-0.06	0.06 -0.14
Manganese	traces -0.10	0.04 -0.10
Silicon	0.02-0.04	0.02 -0.04
Phosphorus	0.04-0.07	0.015-0.022
Sulphur	0.005-0.010	0.005-0.010

Great ductility is characteristic of Swedish charcoal iron, its toughness being higher than that of puddled iron.

A remarkable property of Swedish charcoal iron compared with ordinary mild steel is its comparatively high toughness at temperatures down to 10° F.

Swedish charcoal iron melting bars furnish a good base charge for electric furnaces and crucible steel melting on account of their purity.

H. Von Eckermann, *A Method for Reducing the Percentages of Phosphorus in Swedish Iron by Diminishing the Phosphorus in the Charcoal* (Paper read before the Iron and Steel Institute, May 1925, this Journal, p. 379).

FOUNDRY PRACTICE.

General Foundry Practice.—A. Campion, *General Cupola Design and Practice* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Nov. 27, 1924, vol. 30, pp. 455–458). The factors to be considered in the design and efficient operation of cupolas are discussed. Cupola output will vary to some extent with the nature of the metal, size of scrap, &c., but with a furnace of finely balanced proportions in all parts, and a properly adjusted air supply travelling through the tuyeres at approximately 30 feet per second, there should be melted 16 to 17 cwts. per hour per square foot of cupola area. This corresponds to the most economical rate of coke burning of 180 lbs. per square foot per hour, and requires 25,000 cubic feet of air per hour. It is usual to state the air requirement as so much per ton of metal melted, but this is, in the opinion of the author, to be discountenanced. The air is for the purpose of burning coke to produce the necessary heat, and the air supply should therefore be stated in terms of coke. The usual 30,000 to 33,000 cubic feet of air stated to be necessary to melt a ton of iron is only correct when 2 to $2\frac{1}{4}$ cwts. of coke per ton between charges is used. The volume of air required for different coke consumption is as follows:

Coke per Ton of Iron Melted. Lbs.	Cubic Feet of Air.	Melting Ratio.
224	32,000	1-10
200	28,000	1-11.2
196	27,500	1-11.4
180	25,200	1-12.4
168	23,520	1-13.3
160	22,400	1-14.0

The weight of coke has reference to that placed between charges and exclusive of the bed. A single row of tuyeres should give the best, most regular, and economical working if all parts of the furnace are properly proportioned and the quantity, pressure, and velocity of blast are properly adjusted. Sometimes a second row of tuyeres gives quicker melting by increasing the depth of the melting zone, but to ensure this it is necessary to know the velocity and quantity of air to give the highest possible rate of combustion with one row of tuyeres, and the second row must be so placed that the air injected through them shall act just below the top and less active portion of the combustion zone set up by the lower row of tuyeres. In practice a third row of tuyeres is not effective, as it stands too high and only results in an increased production of carbon monoxide.

J. H. List, *Designing a 4-ton Cupola* (Foundry Trade Journal, Jan. 22, 1925, vol. 31, pp. 71-72). The problems involved in the design of a solid bottom 4-ton cupola are discussed.

M. M. Karnasukhoff, *The Calculation of the "Efficient Height" of Cupolas* (Messager Technico-Economique Russe, Oct.-Nov. 1923, pp. 340-343). The efficient height of a cupola is defined as the portion comprised between the plane of the axes of the tuyeres and the lower plane of the charging orifice. Various formulæ are given for ascertaining what this height should be in the case of cupolas working under given conditions as to diameter, fuel capacity, and rates of driving.

Mechanical Charging for a Foundry Cupola (Iron Age, Nov. 27, 1924, vol. 114, pp. 1397-1398). A short description is given of the methods employed at an American foundry for cupola charging with drop-bottom charging buckets. Particulars are also given of a method of cleaning castings by means of a water-spray. Water at 325 lbs. pressure has effected a large saving in the time required to remove cores from large castings. Labour is reduced and dust eliminated.

Charging Cupolas Mechanically (Foundry, Feb. 1, 1925, vol. 53, pp. 111-113). The method of cupola charging in operation at an up-to-date American foundry is described and illustrated.

E. Piwowarsky and N. Broglio, *Comparative Melting Tests in a Standard Cupola and a Schürmann Furnace of the Same Overall Dimensions* (Die Giesserei: Foundry Trade Journal, Oct. 9, 1924, vol. 30, pp. 305-310). The authors give the results of tests in which two cupolas of the same type were used, one being fitted with Schürmann blast preheaters without any alteration in the furnace dimensions. Heat balances show that the Schürmann cupola is decidedly advantageous from the thermal standpoint. The increase in thermal efficiency amounted to 30 per cent. above that of the standard cupola. The total metallic losses and the power consumed by the blower per ton of iron melted were practically the same in both cases. The Schürmann cupola shows a saving of melting coke of, roughly, 51.5 per cent. and a total saving of coke of 22 per cent. In the Schürmann cupola the iron was 50 to 60° C. hotter and the slag 80 to 100° C. hotter than in the standard cupola. The mechanical and other properties of the iron melted are also considered.

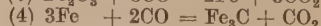
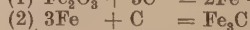
P. Holzhausen, *Heat Balances of an Ordinary Cupola and a Schürmann Cupola Compared* (Giesserei Zeitung, Dec. 1, 15, 1924, vol. 21, pp. 497-504, 520-525). Practical trials on an ordinary cupola and a Schürmann cupola of the same dimensions show that with a fuel consumption of 7.9 kilogrammes of coke per 100 kilogrammes of iron, the Schürmann cupola will produce an equally hot metal as an ordinary one with a fuel consumption of 11.5 kilogrammes of coke to 100 of iron. The melting time of the Schürmann is also shorter, and in the case of the two cupolas working on the same mixtures of iron, the sulphur content of the metal from the Schürmann was 0.083 per cent. compared with 0.11 per cent. in the metal from the ordinary cupola. The losses of

silicon and manganese are about the same in both cupolas, but the loss of iron is somewhat higher in the Schürmann.

H. J. Young, *The Choice and Use of Pig Iron by Modern Methods* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Jan. 8, 1925, vol. 31, pp. 36-37). The paper emphasises the unreliability of the method of grading foundry irons by fracture, and points out the importance of composition in the selection of suitable irons.

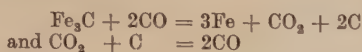
J. E. Fletcher, *The Use of Scrap in Iron and Steel Manufacture* (Foundry Trade Journal, Feb. 12, 1925, p. 144). In the foundry industry a considerable quantity of scrap is lost through not being returned to the foundry for remelting. The average percentage of scrap returned to the iron foundries does not exceed 30 per cent. of the output of castings, therefore 70 per cent. of the mixtures used must be of virgin pig iron. When it is remembered that 40 to 50 per cent. of scrap is often desirable in cast-iron mixtures, fluctuations in the scrap supply produce ever-recurring difficulties. Resort has to be made to steel scrap, and to the remelting of pig iron in order to produce satisfactory scrap for the cupola or other remelting furnace charges. These procedures increase the cost of manufacture, and are not always productive of the results desired. Economically, therefore, estimating on the hypothesis that 25 to 35 per cent. of the casting output is returnable as scrap, it would be reasonable to aim at cupola mixtures containing 30 per cent. of scrap as a maximum. The use of heavy scrap proportions in the cupola charges is unavoidably prejudicial to the quality of the castings made therefrom in that the influence of the increased number of remeltings raises the sulphur content in the iron.

J. E. Fletcher, *Fundamental Factors in the Manufacture and Treatment of Cast Iron* (Paper read before the North-East Coast Institution of Engineers and Shipbuilders, Mar. 13, 1925). The author deals with the fundamental factors of gases, carbon, and temperature in the production of cast iron. It is pointed out that the difference between actual and calculated densities of cast irons of known analysis is probably as being due to gas porosity, the controlling factors in connection with which are carbon, temperature, and gases, influenced by the effect of time and mass. It is suggested that blast-furnace reactions, instead of the form indicated in equations (1) and (2), as follows, are more probably gaseous in character as indicated in (3) and (4) :



The gaseous action in the foundry cupola is also considered in detail, particularly in relation to the remelting of steel and semi-steel scrap. Referring to the suggestion by Honda and Murakami, that graphitisation is probably gaseous in character rather than due to a simple decomposi-

tion of cementite, the author points out that the volume of gas required for the reaction proposed,



is equivalent to 500 cubic feet of CO at 1360° C. and atmospheric pressure per 100 lbs. of grey iron. The major proportion of the graphitisation must be due, therefore, to simple decomposition, although the action may be started by gaseous influence. The separation of primary, secondary, and tertiary graphite at their respective temperatures is described, and the gaseous action in the malleable cast iron annealing process is also described.

F. Hudson, *The Melting and Casting of High-Duty Irons* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Dec. 11, 1924; vol. 30, pp. 495-501). The author discusses many problems involved in the melting and casting of iron for the production of castings which have to withstand both pressure and friction, as in locomotive cylinders. The subject is dealt with under the following headings: Melting in the cupola; cupola reactions; carbonising of metal during descent in cupola; superheating cast iron; conditions for carburisation; melting of heavy duty irons; refractories; pig iron; special pig irons; coke; methods in casting; and pouring temperature.

H. Späthe, *The Use of Open-Hearth Slag as Flux in the Cupola and Air-Furnace* (Stahl und Eisen, Feb. 26, 1925, vol. 45, pp. 297-299). Tests in the use of acid open-hearth slag in the cupola and air-furnace have given very favourable results both metallurgically and economically. The loss of iron is made good by the recovery of the iron in the slag, and the manganese oxides render the cupola slag more fluid and lower the fuel consumption.

Use Sodium Flux for Iron (Foundry, Dec. 15, 1924, vol. 52, pp. 982-984). The use of sodium flux as a desulphuriser in the cupola and ladle is dealt with, and particulars are given of a test carried out with the use of a flux composed of 97 per cent. sodium carbonate and 3 per cent. of sodium hydroxide with a catalytic agent. Examples of the comparatively light and fragile castings poured from sodium-treated metal are illustrated.

Soda Ash as Desulphuriser in Foundry (Iron Age, Feb. 12, 1925, vol. 115, pp. 473-474). Particulars are given of tests carried out by the Griffin Wheel Co., Chicago, manufacturers of chilled iron wheels, on the desulphurisation of iron. Additions of the Walter desulphurising compound were made in the ladle, and the results show that with the correct application of the material it is possible to remove one-third of the sulphur content of the iron. Apart from removing the sulphur, the effect of the treatment is beneficial, for it acts as a cleanser and probably removes oxides, occluded slag, &c., giving a clear appearance to the fracture. There is no evidence to indicate that the physical properties of the cast iron are improved by lowering the sulphur content.

Approximately 90 per cent. of the Walter compound was found to be sodium carbonate, and, from subsequent experiments, it was found that a radical variation from the German formula produces just as satisfactory results. In fact, sodium carbonate alone will produce the necessary reaction. The Griffin Wheel Co. in its regular practice has adopted the use of soda ash, added at the spout rather than in the ladle. In ordinary practice, a considerable proportion of the manganese is lost through the formation of manganese sulphide, which passes off in the slag. By the use of soda ash the manganese is retained.

J. Mehrrens, *Processes for the Desulphurisation, Deoxidation, and Removal of Gases in High Quality Cast Iron* (Stahl und Eisen, Mar. 26, 1925, vol. 45, pp. 449-457). The author reviews briefly various methods for the purification of cast iron, and refers particularly to Walter's method of adding oxides of lime, barium, potash, or soda in a fore-hearth attached to the cupola.

J. Mehrrens, *Desulphurisation, Degasification, and Deoxidisation for High-Duty Cast Iron* (Foundry Trade Journal, Apr. 30, 1925, vol. 31, pp. 376-381). An English translation of the above paper appearing in Stahl und Eisen.

The Improved Peacolt Moulding Machine (Foundry Trade Journal, Mar. 5, 1925, vol. 31, pp. 197-198). The Peacolt machine described is of the turnover type, but, by removal of the turnover table and the substitution of lifting-brackets, is convertible in a few minutes to direct-draw or stripping plate operation.

Recent Developments in Moulding Practice (Engineering Production, Aug. 1924, vol. 7, p. 233). Illustrated particulars are given of the portable and stationary types of the Beardsley-Piper sandslinger moulding machine.

J. M. Sampson, *Making Large Turbine Exhaust Hood Castings* (Foundry, Mar. 15, 1925, vol. 53, pp. 223-226). The methods of moulding and casting cast-iron turbine exhaust hoods at an American foundry are described and illustrated.

J. Shaw, *Makes Heavy Turbine Casing* (Foundry, Oct. 1, 1924, vol. 52, pp. 776-778). A detailed description is given of the methods of moulding employed in producing a 15,000 kilowatt turbine casing in the foundry of the Brightside Foundry and Engineering Co., Ltd., Sheffield.

J. D. Nicholson, *Small Work Moulding in Green and Dry Sand* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Jan. 29, 1925, vol. 31, pp. 92-94, 99). The author emphasises the important features in green and dry sand moulding for the production of reliable moulds and sound castings, and gives some practical hints.

H. Jowett, *Castings for Machine Tools* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Apr. 23, 30, 1925, vol. 31, pp. 341-344, 369-371). Moulding practice in the production of castings for machine tool parts is described and illustrated.

A. S. Beech, *Some Further Reflections on Continental Foundry*

Methods (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, Dec. 18, 25, 1924, vol. 30, pp. 515-518, 537-541). An illustrated description is given of Continental moulding practice and methods of sand preparation and handling.

J. H. Hall, *Proportioning and Shaping of Sink-Heads* (Iron Age, Oct. 2, 1924, vol. 114, pp. 822-823). Far too little attention is paid by foundrymen to the relationship between the weight of a sink-head and that of the casting it is designed to feed. Sink-heads a great deal heavier than is necessary for the proper feeding of steel castings are used in many cases. The author offers some suggestions on this subject, and shows how not only a saving of metal but a lowering of the cost of steel can be secured if the proportioning and shaping of sink-heads is carefully studied. The advantages to be obtained in the use of a cone-shaped head are described.

F. C. Edwards, *Gates and Risers* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, Apr. 30, May 7, 1925, vol. 31, pp. 365-368, 395-397). The author discusses the general principles which govern the efficient employment of gates and risers.

J. W. Frier, *The Use of Chills in Marine Engine Castings* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, Mar. 26, 1925, vol. 31, pp. 265-270). The author describes his experiences in the use of chills for marine engine castings.

G. Edginton, *Oil Sand Cores* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, Apr. 9, 1925, vol. 31, pp. 315-316). The preparation and use of oil sand cores are discussed.

H. Ryner, *Heating and Drying in Foundries* (Foundry Trade Journal, Jan. 1, 1925, vol. 31, pp. 15-16). A description is given of Oehm's heating element and its application to the drying of moulds and cores and the heating of ladles.

J. Freygang, *Kish in Cast Iron* (Giesserei Zeitung, Feb. 1, 1925, vol. 22, pp. 70-71). The author discusses the conditions leading to the formation of kish on the surface of castings, and the means for its prevention.

J. Longden, *Some Considerations on Liquid Shrinkage in Grey Iron* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, Mar. 12, 1925, vol. 31, pp. 219-225). The phenomenon of liquid shrinkage in grey iron castings is discussed. The shrinkage of grey iron is about 4.5 per cent. of its liquid volume on crystallisation. If the expansion which immediately follows crystallisation be directed wholly inwards there is a residual loss in volume, due to liquid shrinkage, of about 1.5 per cent. Quick cooling, as by the use of chills, does not reduce the rate of liquid shrinkage, but makes for greater solidity only if solidification is so speeded up thereby as to enable new metal to reach the part concerned. Slow pouring does not reduce the rate of liquid shrinkage, but may alter its distribution throughout the casting. The aggregate loss of volume due to liquid shrinkage does not appear to be appreciably affected by composition or temperature of pouring.

P. Bardenheuer and C. Ebbefeld, *An Examination of the Shrinkage Process in White and Grey Cast Iron* (Mitteilungen a.d. Kaiser-Wilhelm-Institute für Eisenforschung, 1925, vol. 6, part 6, pp. 45-60). Measurements of volume changes were made with an improved apparatus. The phenomenon of initial expansion is considered to have some relation to the gases contained in the molten mass. The effect of the various usual constituents of cast iron on the degree of shrinkage is considered.

F. C. Edwards, *Contraction Stress : Cause and Remedies* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, Dec. 18, 1924, vol. 30, pp. 519-522). A discussion of the causes of contraction stress in castings.

H. Endo, *The Measurement of the Change of Volume in Metals during Solidification* (Science Reports of the Tôhoku Imperial University, Nov. 1924, vol. 13, pp. 193-227).

I. Lamoureux, *Molecular Equilibrium in Grey Iron Castings* (Paper read before the Congress of the Association Technique de Fonderie : Foundry Trade Journal, Dec. 18, 1924, vol. 30, pp. 524-525). The prevention of internal stresses set up by contraction in castings is briefly discussed.

Some Methods of Overcoming Contraction and Sullage Troubles (Foundry Trade Journal, Jan. 8, 1925, vol. 30, pp. 25-27). Practical methods for avoiding stresses due to contraction and other imperfections in castings are described.

J. Gray, *Contraction and Warping in Castings* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, Oct. 23, 1924, vol. 30, p. 348).

I. Lamoureux, *White Deposits on Castings* (Revue de Fonderie : Foundry Trade Journal, Jan. 15, 1925, vol. 31, pp. 45-47). The author discusses the formation and prevention of white deposits appearing on the upper and horizontal faces of the massive portions of iron castings poured in dry sand. The presence of these deposits is not harmful, and they are generally removed in the machining. They appear to be composed for the most part of silica, and are caused by the slow cooling of high phosphorus and siliceous metals.

E. Longden, *An Analysis of Defective Castings* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, Mar. 5, 12, 1925, vol. 31, pp. 208-210, 229-232). A discussion of the nature and causes of defects met with in grey iron castings.

Castings for Diesel Engines (Foundry Trade Journal, Dec. 4, 1924, vol. 30, pp. 475-480). At a joint conference held in Glasgow under the auspices of the Institute of British Foundrymen and the Institution of Mechanical Engineers, the four following papers were presented, in which were discussed the problems associated with the production of castings for oil engines :

A. L. Mellanby, *Temperature Stresses and Working Conditions in Diesel Engine Cylinders*.

A. Campion, *Some Characteristics of Cast Iron for Oil Engine Castings*.

J. Richardson, *Oil Engine Design as Affected by Foundry Practice*.

W. Bell, *Oil Engine Design from a Foundryman's Point of View*.

J. Ward, *Controlling Grey Iron Qualities* (Foundry, Mar. 1, 1925, vol. 53, pp. 186-188). The influence of various elements on the structure and strength of grey iron is discussed.

J. Goostray, R. F. Harrington, and M. A. Hosmer, *Brief History of Metallurgical Practice in Cannon-making, with Particular Reference to the Cast Iron Gun* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). The authors review the subject from the earliest times, outlining three epochs in the history of making cannon, and describe the plants and operations of early American foundries. The adoption of alloy steel for guns, modern high-power guns, and the German long-range gun are also briefly dealt with.

R. E. Nelles, *Reducing Cost on Soil Pipe* (Foundry, Feb. 1, 1925, vol. 53, pp. 100-102). The outstanding features of pipe-founding practice at the plant of the National Foundry Co., Brooklyn, New York, are described and illustrated. The most radical departure from the orthodox method of moulding soil-pipe castings is the adoption of a type of a flask in which eight castings are made at one time, as contrasted with the ordinary type of flask, in which only two casts are made side by side.

J. T. Mackenzie, *The Electric Furnace in the Pipe Foundry* (Paper read before the American Foundrymen's Association, Oct. 1924). The author describes electric furnace practice for the production of iron for pipes.

H. Etchells, *The Prospects of the Electric Furnace in Iron, Steel, and Brass Foundries* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, May 7, 1925, vol. 31, pp. 392-394).

L. J. Barton, *Refining Metals Electrically* (Foundry, 1924, vol. 52, Oct. 1, pp. 782-784, 788, Oct. 15, pp. 813-816, Nov. 1, pp. 861-864, Nov. 15, pp. 897-899, Dec. 1, pp. 932-936, 951, Dec. 15, pp. 967-970, 977, 1925, vol. 53, Jan. 1, pp. 9-13, Jan. 15, pp. 70-72, Feb. 1, pp. 103-107, Feb. 15, pp. 150-154, 160, Mar. 1, pp. 189-192, Mar. 15, pp. 233-236, Apr. 1, pp. 272-274, Apr. 15, pp. 239-331.) A continuation of a series of articles describing electric furnace practice, with special reference to foundry work.

W. Ruddy, *French and American Iron Foundry Methods Compared* (Foundry, February 1, 1925, vol. 53, pp. 97-99).

Synthetic Iron.—V. Stobie, *The Electric Furnace in the Iron Foundry* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, May 7, 1925, vol. 31, pp. 398-400). The author points out the advantages of the electric furnace for use in the iron foundry. The production of synthetic iron and semi-steel and the refining of pig iron are briefly discussed.

K. Kerpely, *The Electric Furnace in the Iron Foundry* (Giesserei

Zeitung, Feb. 1, 1925, vol. 22, pp. 61-65). A description of general practice in the production of ordinary cast iron and synthetic iron in the electric arc furnace. A duplex process consisting of a cupola furnace working in combination with an electric furnace is also described. This process offers great advantages where the iron and coke are not of the best quality. The metal after melting in the cupola can be tipped into the electric furnace, where it is desulphurised and the necessary quantity of ferro-silicon and ferro-manganese is added according to the desired quality of iron.

K. Kerpely, *The Manufacture of Synthetic Cast Iron from Scrap* (Giesserei Zeitung, Apr. 15, 1925, vol. 22, pp. 213-218). Describes the manufacture of synthetic cast iron from cast scrap, steel turnings, and other steel scrap in a 3-ton Heroult furnace. The consumption of power is about 6.50 kilowatt-hours per ton of castings produced.

E. L. Willson, *Electric Furnace Grey Iron* (Paper read before the American Foundrymen's Association, Oct. 1924). The author discusses experiments in the production of grey iron castings from steel scrap. The primary object was to produce synthetic pig iron from steel scrap, utilising off-peak power at a price to compete with the blast-furnace product used by iron foundries. It was also desired to determine the relative cost and metallurgical characteristics of synthetic grey iron made direct into castings as compared with those produced in foundries by the cupola process. Both acid and basic processes were used. The experiments show that synthetic grey iron may be produced in the electric furnace under favourable conditions at a price equal to or lower than that of the better grades of cupola iron. Castings produced from synthetic grey iron show a much higher degree of purity, physical strength, and toughness than the best cupola iron.

Semi-Steel.—H. Field, *Semi-Steel* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Apr. 9, 1925, vol. 31, pp. 309-314). The author discusses some of the principles underlying the production of semi-steel.

Basic Principles Underlying the Manufacture of Semi-Steel (Foundry Trade Journal, Apr. 9, 1925, vol. 31, pp. 306-308). The absorption of carbon by steel in the cupola, the effect of steel additions, and the mechanical properties of semi-steels are discussed and some practical hints on the preparation of semi-steel mixtures are given.

G. W. Gilderman, *Semi-Steel* (Blast-Furnace and Steel Plant, Nov. 1924, vol. 12, p. 526). Notes on practice in producing semi-steel in the cupola are given. The following is recommended as a mixture to produce a casting having a thickness of $\frac{3}{4}$ inch. The analysis of the casting should be silicon 1.60, manganese 0.75, phosphorus 0.40, and sulphur about 0.09 per cent. To obtain this the charge should consist of pig iron 60, steel scrap 20, and cast scrap 20 per cent. The pig iron should analyse as follows: Silicon 2.30, manganese 1.25, phosphorus about 0.40, and sulphur less than 0.05 per cent. If the manganese in the

pig iron is too low, ferro-manganese may be added in the cupola to make up the deficiency.

Steel Foundry Practice.—S. H. Bunnell, *Special Open-Hearth Castings* (Iron Age, Mar. 26, 1925, vol. 115, pp. 901-903). Particulars are given of the construction of the Bosshardt open-hearth furnace for the production of steel for castings. The furnace has the usual regenerative checkerwork, and is fired with gas from small producing chambers built directing on the two ends of the furnace. Slots are provided in the furnace walls, connecting with the producers. Temperatures above 4000° F. are easily maintained in this furnace.

E. A. Hanff, *Multiple System of Electric Melting* (Iron Age, Oct. 16, 1924, vol. 114, pp. 999-1003). An illustrated description of the operation of twin electric furnaces at an American steel foundry. Two furnaces are mounted on a turntable having one set of electrodes common to both furnaces.

H. Hermanns and H. Meixner, *Making Hard Manganese Steel* (Iron Trade Review, Feb. 12, 19, 1925, vol. 76, pp. 452-454, 509-511; Foundry Apr. 15, 1925, vol. 53, pp. 323-325). The authors discuss the production and properties of hard manganese steel castings. The hardness and dependability of the material is contingent upon the manganese content, and the toughness depends upon the subsequent heat treatment of the castings. Without this heat treatment the hard manganese steel is brittle and shows tensile values which are not uniform. The phosphorus and sulphur contents should not exceed 0.07 per cent., while the carbon content should range between 0.75 and 1.50 per cent. As a general rule, the manganese content should not be less than 12 per cent. nor exceed 13 per cent. Hard manganese steel, although showing a Brinell hardness of about 225, gives the best possible resistance to wear. Special importance is attached to the addition of ferro-manganese, which should be as low in phosphorus as possible. For carburising the bath petroleum coke or electrode scrap are used. For thick-walled castings a carbon content ranging from 1.15 to 1.20 per cent. is suitable, while for thin-walled castings a carbon content of 1.30 per cent. is best, the manganese content being the same in both cases. The methods of heat treatment are also described.

J. M. Quinn, *Making Cast Manganese Steel* (Foundry, Dec. 15, 1924, vol. 42, pp. 964-966). The author outlines electric furnace practice for the manufacture of manganese steel. Rapid melting and the method of making slag and alloy additions play an important part in producing satisfactory steel. Brief particulars are given of the methods of heat treatment.

V. Zsak, *Experience in Steel Foundry Practice* (Giesserei Zeitung, Mar. 1, 1925, vol. 22, pp. 113-117). The author gives notes on general practice in steel foundry work, including the use of stopper ladles and the production of castings from the converter, the open-hearth and the electric furnace.

Moulding Sands.—C. A. Hansen, *The Physical Properties of Foundry Sands* (Paper read before the American Foundrymen's Association, Oct. 1924). The author has carried out an investigation in an endeavour to correlate most of the measurable properties of a few simple foundry sands. The following properties were studied : green bond (Doty test), green compression strength, dry cross-bending and dry compression strength, green and dry permeabilities, and green and dry densities. The author concludes that green strength is primarily a surface tension affair. Numerically it is a measure of the amount of increased water surface created by the displacement of the sand grains during rupture of a core. It is often confused with viscosity, as in the case where various organic binders are added to core sands to give them apparent strength. Green strength may determine moulding characteristics, but rather in the way that high green strength involves sand that will not flow laterally beneath a rammer and thus leads to non-uniform rammed moulds and scabbed castings. It has no bearing on the capacity of the mould to withstand the action of molten metal. Dry strength determines the capacity of a mould to withstand molten metal.

A. Tauffier, *The Experimental Examination of Moulding Sand* (Paper read before the Congress of the Association Technique de Fonderie : Foundry Trade Journal, Dec. 25, 1924, vol. 30, pp. 548-549). The author outlines simple and direct tests that can be carried out in the foundry, at the same time giving definite and useful information on the quality and suitability of the various sands employed.

J. Behr, *The German Moulding Sands, their Distribution and Testing* (Giesserei Zeitung, Jan. 15, 1925, vol. 22, pp. 37-43). The author describes investigations on moulding sands, made to determine the refractoriness, the plasticity, and permeability. The fusion point of moulding sands was determined in an electrically heated furnace, using Seger cones for judging the temperature at which the sand fuses. A sand is classed as refractory if it melts at cone 27. The plasticity depends on the proportion of quartz sand to the binding constituents, such as colloid clay, iron oxides, and free alumina, and methods for determining the colloid substances are described. By determining the hygroscopicity the colloids can be indirectly estimated, and this method is much more reliable than the colour method.

K. Gripp, *The Properties and Origin of Moulding Sand* (Giesserei Zeitung, Mar. 15, 1925, vol. 22, pp. 166-168).

Aulich, *The Knowledge of Moulding Sand and its Importance in Foundry Technology* (Die Giesserei, Nov. 8, 1924, vol. 11, pp. 737-741). A discussion of the plasticity, strength, permeability, and refractoriness of sands. With notes on the origin, composition, and testing of moulding sands, including the colour-absorption test.

L. Deltour, *A Review of the Physical Properties Involved in a Study of Moulding and Foundry Sands* (Paper read before the Paris Foundry Congress : Foundry Trade Journal, Jan. 22, 1925, vol. 31, p. 66).

C. M. Nevin, *Grading of Moulding Sands* (Paper read before the American Foundrymen's Association, Oct. 1924).

H. C. Dews, *The Grain-Size Grading of Moulding Sand* (Foundry Trade Journal, Nov. 13, 1924, vol. 30, pp. 413-415). The three common methods of grading moulding sand according to grain size—screening, elutriation, and sedimentation—are discussed.

C. M. Nevin, *The Relation of Water to the Bonding Strength and Permeability of Moulding Sands* (Transactions of the American Foundrymen's Association, 1924, vol. 32, Part 2, pp. 168-181).

T. C. Adams, *Testing Moulding Sands to Determine their Permeability* (Transactions of the American Foundrymen's Association, 1924, vol. 32, Part 2, pp. 114-167). Apparatus and methods for testing the permeability of moulding sands are described.

A. A. Grubb, *Controlling Moisture in Sand* (Foundry, Feb. 15, 1925, vol. 53, pp. 145-147). A detailed description is given of apparatus and methods used in the determination of moisture in moulding sand.

R. F. Harrington, A. S. Wright, and M. A. Hosmer, *A Study of Various Moulding Sand Mixtures together with the Physical Properties of the Moulds and the Castings Produced* (Paper read before the American Foundrymen's Association, Oct. 1924).

E. Ronceray, *New French Mould Hardness Tester* (Paper read before the American Foundrymen's Association, Oct. 1924). A description is given of a ball hardness machine for testing sand moulds and cores.

Centrifugal Casting.—*Centrifugal Cast Pipe* (Iron Age, Dec. 25, 1924, vol. 114, p. 1674). Brief particulars are given of the Henry-Weitling-Peake process for the production of centrifugally cast pipe, the inventors of which claim to have solved the problem of producing a soft grey iron casting in a rotating permanent mould which does not require subsequent annealing. The process involves the employment of liquid mercury and mercury vapour.

Cleaning of Castings.—A. Rutherford, *Cleaning Castings* (Foundry Trade Journal, Jan. 22, 29, 1925, vol. 31, pp. 79, 99). The cleaning of castings is discussed, with special reference to the tentative regulations drawn up by the Home Office.

W. M. Weigel, *Preparing Sands for Blasting Uses* (Iron Trade Review, Sept. 25, 1924, vol. 75, pp. 803-804). The preparation of sands used in sand-blasting is briefly discussed.

Malleable Cast Iron.—A. Hayes and W. J. Diederichs, *Possibilities of Producing Malleable Iron and Intermediate Products of Value in Short Annealing Periods* (Transactions of the American Society for Steel Treating, Oct. 1924, vol. 6, pp. 491-498). In a previous paper (Mar. 1923, vol. 3, p. 624) the authors give the results of experiments carried out in an endeavour to shorten the annealing time for the malleabilisation of white cast iron. The present paper gives the results

of experiments made with the object of shortening still further the annealing cycle for complete graphitisation of white iron, and for studying the conditions for the production of intermediate products. Test-bars^{*} were placed on end, unsupported and unpacked, in an L. and N. hump furnace, the temperature of which was 1700° F. The temperature dropped to 1200° F., and it required forty minutes for it again to reach 1700°. This temperature was maintained for three hours, and it was then lowered to 1560° F. in one hour. Then the cooling rate was reduced, so that the bars cooled uniformly and slowly to 1320° F. at 17° per hour. The rate of cooling was then further reduced to 10° per hour, so that the bars cooled to 1200° F. in another twelve hours. The process was considered complete when this temperature was reached, the overall time required for complete graphitisation being thirty-one hours. It is believed that an application of the same principles as above outlined will allow a more rapid cooling between the high temperature and 1560° F. Also it is considered almost certain that material can be removed from the furnace at temperatures higher than 1200° F. without interfering with the resulting properties. The relations between the method of treatment, microscopic structures, and physical properties are discussed.

D. Wilkinson, *Malleable Cast Iron* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Jan. 8, 1925, vol. 31, pp. 28-32). General practice in the production of malleable cast iron is discussed. The paper is confined almost entirely to castings produced from the cupola.

Malleable Cast Iron (Metal Industry, Dec. 5, 12, 19, 26, 1924, vol. 25, pp. 551-553, 575-577, 595-597, 617-618, Jan. 2, 9, 1925, vol. 26, pp. 11-12, 39). A series of articles dealing with the nature and development of malleable cast iron, and a discussion of the chief considerations in its manufacture.

The Manufacture of American Blackheart Castings (Metal Industry, Apr. 24, May 1, 1925, vol. 26, pp. 413-415, 443-445). The chief production and metallurgical problems in the manufacture of blackheart malleable castings, particularly those relating to annealing temperatures, are dealt with.

S. J. Felton, *Annealing Malleable Cast Iron* (Iron Age, Feb. 12, 1925, vol. 115, pp. 489-490). Brief particulars are given of the results of tests carried out in order to determine the effect of rapid heating.

R. N. Richardson, *Malleable Castings* (Engineering Production, Oct. 1924, vol. 7, pp. 311-312). Brief notes are given on the properties and manufacture of malleable castings.

Builds Coast Malleable Plant (Iron Trade Review, Nov. 20, 1924, vol. 75, pp. 1375-1380; Foundry, Jan. 15, 1925, vol. 53, pp. 56-60). An illustrated description is given of the new malleable casting foundry of the Pacific Malleable Casting Company, Oakland, California. All the departments are housed in one building, and are situated one to the other in the sequence of operations, thus eliminating any back-tracking

of the work in process. Practically all the handling is done with a lifting magnet.

Foundry Equipment.—*Works of Llanelly Foundry and Engineering Company, Ltd.* (Iron and Coal Trades Review, Feb. 27, 1925, vol. 110, p. 353; Foundry Trade Journal, Apr. 9, 1925, vol. 31, pp. 301–304). A description is given of this foundry for the production of chilled and grain rolls, ingot moulds, and general iron castings.

New Iron Foundry at the Darnall Works of Messrs. Davy Brothers, Ltd. (Iron and Coal Trades Review, Apr. 3, 1925, vol. 110, pp. 544–546). The equipment of this iron foundry is described and illustrated.

L. S. Love, *Steel Foundry Practice at Schenectady* (Iron Age, Oct. 2, 1924, vol. 114, pp. 815–819). Steel foundry practice at the Schenectady Works of the General Electric Co. is described and illustrated. The foundry is equipped with two Héroult furnaces of 6 and 5 tons capacity respectively. The production of nozzle diaphragm castings is one of the outstanding features of the foundry, although brake wheels and elevator motor shafts are also produced.

G. L. Lacher, *Studebaker Grey Iron Foundry* (Iron Age, Oct. 2, 1924, vol. 114, pp. 835–842). A detailed illustrated description is given of the lay-out and equipment of the grey iron foundry of the Studebaker Corporation, South Bend, Indiana, which is stated to be the largest unit foundry in the United States.

F. L. Prentiss, *Foundries of Automobile Builder* (Iron Age, Apr. 9, 23, 1925, vol. 115, pp. 1035–1040, 1199–1202). An illustrated description is given of the general lay-out and equipment of the new iron, aluminium, and brass foundries at the plant of the Cadillac Motor Car Co., Detroit.

P. Dwyer, *Makes Heavy Steel Castings* (Foundry, Jan. 15, 1925, vol. 53, pp. 61–67). The general lay-out and equipment of the steel foundry of the Dominions Foundry and Steel Co., Hamilton, Ontario, are described and illustrated. This concern is one of the leading producers of steel castings in Canada. Exceptionally large castings, used in railway construction and power generation, are produced.

P. Dwyer, *Canadian Company Produces Large Electrical Castings* (Foundry, Apr. 1, 1925, vol. 53, pp. 276–280). An illustrated account of the methods employed at the foundry of the Westinghouse Electric and Manufacturing Co., Hamilton, Ontario, for the production of large castings used in the electrical industry.

P. Dwyer, *Makes Machine Tool Castings* (Foundry, Dec. 15, 1924, vol. 52, pp. 957–962). An illustrated description is given of the equipment and methods employed at a modern American foundry for the production of machine tool castings.

Study of Foundry Building Design (Iron Age, Nov. 20, 1924, vol. 114, pp. 1334–1337). Factors to be considered in the selection of foundry sites and the lay-out and equipment of foundries are discussed.

Continuous Moulding and Casting (Iron Age, Jan. 15, 1925, vol. 115,

pp. 187-191). The methods employed at the plant of the Warren Foundry Co., Warren, Ohio, are described and illustrated. One of the most outstanding features is the method of pouring the moulds. A system of conveyors carry the moulds to the cupolas, where specially designed ladles are used to pour the moulds during transit on the conveyor. The speed of the conveyor through the pouring zone is 8 to 12 feet per minute.

P. Dwyer, *Mechanical Aids Handle Sand in Manganese Shop* (Foundry, Feb. 15, 1925, vol. 53, pp. 140-144, 160). The sand-handling equipment installed in a large Chicago steel foundry is described and illustrated.

P. Dwyer, *Tunnels Facilitate Handling of Material in New Foundry* (Iron Trade Review, Oct. 2, 1924, vol. 75, pp. 879-883, 897). An illustrated description is given of the lay-out of the new foundry of the Studebaker Corporation, South Bend, Indiana, and the methods of handling materials. One of the distinctive features of the foundry is the system of tunnels under the floors which serve as main traffic arteries and prevent congestion on the main floor.

Decrease in Foundries Noted (Foundry, Oct. 15, 1924, vol. 52, pp. 801-805). Statistics are given showing the number and location of foundries in the United States and Canada.

PRODUCTION OF STEEL.

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I.—PROCESSES OF STEEL PRODUCTION.

Crucible Steel.—*A New Type of Crucible Melting Plant* (Foundry Trade Journal, Feb. 26, 1925, vol. 31, p. 190). A new type of coke-fired crucible furnace for steel making, introduced by the Morgan Crucible Company, is described and illustrated.

J. A. Mathews, *Comments on the Making and Use of Alloy Tool and Special Steels* (Transactions of the American Society for Steel Treating, Feb. 1925, vol. 7, pp. 147–170). This paper constitutes a general résumé of the development of the tool steel industry. The various melting methods used in producing tool steel are briefly dealt with, and a discussion of the various elements used in the production of a high-grade product is touched upon. The author discusses the subject of chemical specifications as a basis for the purchase of tool steels, pointing out that such a method of buying tool steel places an unnecessary burden upon the buyer.

H. Neuhauss, *Note on Cement Bar for Use in the Production of Crucible Steel* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1664–1668). An investigation of the gases from cementation boxes, of the behaviour of oxides and silicates in the cementation process, and of the results of annealing in vacuum at 1120° to 1160° C., shows that cementation bar steel is practically free from oxygen.

F. T. Sisco, *The Chemistry of Iron and Steel* (Transactions of American Society for Steel Treating, May 1925, vol. 7, pp. 640–656). The chemistry of wrought iron and crucible steel is described, and the nature of the defects in iron and steel introduced during melting or refining and working is discussed.

Bessemer and Open-Hearth Processes.—Platon, *Views on the Technical Future of the Bessemer Process* (Revue de Métallurgie, Oct. 1924, vol. 21, pp. 628–633). A well-made basic Bessemer steel is not appreciably inferior to ordinary basic open-hearth steel in respect of tensile strength, elongation, forging, rolling, or welding properties, impact resistance, bending tests, or brittleness. Chemical analysis

alone does not serve to establish the quality of a steel, and often fails to explain defects. This is because routine analyses seldom record all the chemically important constituents, notably the oxygen present. It would appear that it is this oxygen, combined with the iron and apart from that which may be in combination with other metals or metalloids present, which constitutes the injurious factor, rendering, when in excess, the metal red short and otherwise mechanically inferior. It is the degree of oxidation to which in a Bessemer converter the metal is exposed, and a knowledge of how to deoxidise it, which turned the Bessemer process, at first unsatisfactory, into a successful method. Broadly speaking, crucible steel contains no surplus and injurious oxygen; good open-hearth metal, traces only (0.010); less good open-hearth metal is often more oxidised (0.030 per cent.), and Bessemer metal often contains much oxide (0.060 per cent.). When higher, the metal is, in either case, bad of its class. The influence of other impurities is, moreover, accentuated by the presence of oxygen; sulphur, for instance, is objectionable only if oxygen be present. If it were possible, by ideal casting, to obtain metal without appreciable segregation, the main objections to sulphur and phosphorus would disappear, and oxygen would be revealed as the most serious of the impurities. The art of the blower is to dephosphorise without oxidising the iron. The chemistry of the process is examined in some detail, and the function of the slag is discussed, from the point of view of dephosphorisation. The essential would seem to be to protect the converter metal from unnecessary decarburisation and from oxidation by working the charge so that an active slag shall be formed at the earliest possible stage. Various methods for the formation of such a slag have been put forward from time to time, and the addition of iron oxide itself, mixed with the lime, has been tried. The problem really involves the rapid heating up of the slag. All additions to the charge should be broken as small as possible to facilitate this heating up. A liquid slag might, alternatively, be introduced. This slag would, of course, have to be previously melted in another vessel and poured into the ladle before the introduction of the molten pig iron. This would entail, of course, wide departures from current practice, yet it is along such lines that progress in the manufacture of Bessemer metal is to be sought, and will, in all probability, be attained.

F. Diesfeld, *New Process for the Manufacture of Converter Bottoms on Jarring Machines* (Stahl und Eisen, Feb. 19, 1925, vol. 45, pp. 259-261). A machine on the same principle as a moulding jarring machine has been devised for the production of converter bottoms, both acid and basic. The apparatus is illustrated and the operations are described. A considerable economy in labour is secured and the average life of the bottoms is increased from 26.2 to 54.2 heats, or just about 100 per cent.

E. Diepschlag, *General Observations on the Construction of Open-Hearth Furnaces* (Zeitschrift des Vereines Deutscher Ingenieure, Nov. 29, 1924, vol. 68, pp. 1233-1236). The author discusses the various modes

of heat-transmission and the application of the theory of heat-transmission to the design and working of open-hearth furnaces. Various types of ports and regenerators are shown, including the Bernhardt port, the Maerz port, and the Moll construction in two forms.

J. A. de Grey, *Considerations as to Modern Open-Hearth Furnaces* (Revue de Métallurgie, Mémoires, June 1924, vol. 21, pp. 338-339). A comparison between American and French open-hearth furnace design and practice. In the United States water and air cooling is adopted to a far greater extent than in France, and heat losses by radiation are proportionally greater, while the furnace yield is diminished. The heat losses in the stack are, on the other hand, reduced by the fuller employment of waste-heat boilers. On the Continent, where little is done in this direction, the gases escape at much lower temperatures than in America. The saving in American practice may be regarded as equal to about 10 per cent. of the calories. The salient points of difference in design and practice are noted, and a comparative table showing the usual dimensions employed both in American and French furnaces of 100 tons capacity. From the figures given it appears that the average number of charges worked in French practice is higher per week than in America, the ratio in favour of France being as 3 : 2. The coal consumption is also distinctly lower in French practice, the coal consumed per ton of steel being, in the American furnaces, 260 to 280 kilogrammes, and in the French furnaces only 210 to 230 kilogrammes.

J. A. de Grey, *Modern Martin Furnaces* (Chimie et Industrie, May 1924, pp. 297-305). The author has studied the design of a modern steel-making plant, and compares American and European furnaces.

H. Bansen, *Measurements and Outputs of German Open-Hearth Furnaces* (Stahl und Eisen, Apr. 2, 1925, vol. 45, pp. 489-507). The paper is an important contribution to the knowledge of open-hearth construction and practice in relation to the output of steel. By means of a circular inquiry data concerning fifty-six open-hearth furnaces were obtained from twenty-seven works. Measurements were obtained of all the important dimensions of furnaces, as well as of air and gas velocities, and weights and cubic space of checkers. Altogether some hundred and fifty values are tabulated for each of the fifty-seven furnaces. The furnaces are grouped, not according to their rated tonnage, but according to their output per hour, and the author endeavours to correlate the numerous factors with a view to finding the most favourable dimensions, weights, and inputs of heat, and how far the furnace efficiency is affected by variations of these. Certain clear relations are established between some of the factors, but for the most part it would appear that furnace design, particularly as regards regenerators, heating surfaces, and area of flues and uptakes, follows no fixed rule. Some comparatively small furnaces of indifferent design are found to give quite good outputs, and this is ascribed to the skill and scientific knowledge on the part of the furnace men. On the other hand, a very great deal depends on the proper proportioning of the

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weight of charge, hearth area and depth, total weight of checkers and the weight of checkers per cubic metre of space occupied, and areas of gas and air ports.

F. J. Crolius, *The Open-Hearth in 1924* (Blast-Furnace and Steel Plant, Jan. 1924, vol. 13, pp. 42-45). The author presents a general consideration of the open-hearth as a combustion unit, giving illustrations and criticisms of furnaces of the Danforth restricted type with natural draught, of the Egler and of the McKune type, using forced draught with water-cooled valves, and the Loftus type, which has no valves in the furnace itself. The feature of the Loftus furnace is the introduction of a jet of hot air into the centre of the stream of gas just at the point where this is directed downwards into the furnace. The pressure of the air aspirates the gas, and combustion is set up between the central core of air and the ring of gas about it. The melting proceeds very rapidly, and there is a material reduction in fuel cost per ton of steel and an increase in tonnage.

Groume-Grjimaïlo, *On the Theory of Flame Furnaces* (Chaleur et Industrie, Oct. 1924, pp. 511-514). A short recapitulation of the author's latest views of flame action in reverberatory and other furnaces, with special reference to open-hearth working. The behaviour of open-hearth furnaces does not depend entirely on its design, the type and arrangements of the ports, and dimensions, but the main factor is to supply sufficient heat for its needs; furnaces of this kind fall into one of two categories—those which get enough heat, and those which do not. The whole behaviour and coal consumption of an open-hearth furnace are subsidiary to the one point. Are the flames hot enough, and are they effectively directed to secure the best conditions of radiation, conduction, and convection?

T. Sunnen, *The Air and Gas Consumption in the Recuperative Chambers attached to Flame Furnaces* (Chaleur et Industrie, Feb. 1925, pp. 55-61). A mathematical investigation of the efficiency of relative volumes of gas and air admixture, on the lines of Groume-Grjimaïlo's work, illustrated by diagrams and establishing a number of formulæ applicable to various conditions and to different types of furnace, recuperators, ports, and chequers.

W. Hülbruch, *Gas Reactions in the Regenerators of an Open-Hearth Furnace Fired with a Mixture of Blast-Furnace and Coke-Oven Gas* (Mitteilungen aus der Versuchsanstalt d. Deutsch-Luxemburgischen Bergwerks u. Hütten A.G., Dortmund, 1924, vol. 1, pp. 131-152). The heating of the mixture of gases in the regenerators brings about an increase in the proportion of hydrogen and carbon monoxide in the gases, and part of the carbon becomes deposited in the checkers, the amount being dependent on the temperature, the rate of flow of the gas and on its composition. By heating the gas to 1000°-1100° C. and delaying its passage through the regenerator, a portion of the carbon first deposited is reconverted into carbon monoxide and the calorific power of the gas is maintained.

K. Huffelman, *Attainment of High Efficiency in Combustion of Fuel* (Stahl und Eisen, Nov. 20, 1924, vol. 44, pp. 1488-1491). In a metallurgical furnace the chief requirement in the matter of fuel economy is a maximum transmission of heat to the charge rather than a steep temperature gradient between the fuel gases and the bath, the two requirements being by no means identical. The transmission of heat is not dependent on the temperature alone, but on the time during which the charge is exposed to the burning fuel and on the eddying of the gases, and it is effected by conduction and convection as well as by radiation. Perfect mixing of the air and gas is essential to economic combustion. The burners commonly in use are those burning a cold gas and air mixture with or without a chamber for preliminary mixing, and those for burning a hot mixture, with automatic air admission or with artificial means for supplying air. With burners using a cold mixture the essential conditions for good combustion are that the rate of flow of the gas and air mixture must just equal the rate of ignition, which varies according to the temperature of the mixture, and the gas must be set flowing freely so as to transform its pressure fully and without loss into a current with sufficient energy to draw in automatically the requisite quantity of air. The best burners are of refractory material subdivided into a number of openings.

P. Kersten, *Recuperation of Heat Losses in an Open-Hearth Furnace* (Revue Universelle des Mines, May 1, 1925, vol. 6, pp. 144-159). The heat balance sheet of a 30-ton open-hearth furnace is given, working on producer-gas and charged with cold materials. No less than 83 per cent. of the heat received, calculated from the coal consumed in the producers, is returned as lost, either by radiation and conduction, or in the chimney gases. The thermal efficiency of the furnace is thus only 17 per cent. The coal consumed works out at 265 kilogrammes per ton of steel made. The producer efficiency is 85 per cent. Radiation losses are higher in proportion to the convection losses in small furnaces than in large ones, for reasons which are duly given. A table is also given of the coefficients of conductivity for different refractories. Proposals have been made to provide channels for the air in the roof itself, but with the refractory materials currently in use such an expedient would be difficult and dangerous. Hitherto no satisfactory method of combating the radiation and conduction losses has been found. The escaping gases should, theoretically, not exceed 300° C. in temperature. In practice they are seldom below 500°, and range to 700°. With coke-oven or blast-furnace gases this temperature can be reduced. The heat lost in the stack subserves a useful purpose as it assists draught. Otherwise the resistance to the gas offered by the checker-work and the ports would be excessive. The advantages and disadvantages of waste-heat boilers in this connection are discussed in detail, and the most suitable types considered, with examples of heat balances derived from actual results.

G. Bulle, *Efficiency Degree in the Working of a Siemens Furnace*

(Stahl und Eisen, Oct. 23, 1924, vol. 24, pp. 1324–1326). Mathematical calculations are given to determine the metallurgical efficiency, the furnace efficiency, and the gas-producer efficiency in an open-hearth plant.

The Physical Chemistry of Steel-Making Processes. At a joint meeting of the Faraday Society and the Iron and Steel Institute held on June 8, 1925, the nine under-mentioned papers were presented. The papers will be published in full, together with discussion, in a forthcoming volume of the Transactions of the Faraday Society:

Sir Robert Hadfield, *Physical Chemistry in Steel-Making.*

A. McCance, *Balance Reactions in Steel Manufacture.*

J. B. Ferguson, *Equilibria in Systems involving Ferrous Oxides.*

P. McNair, *Slag Reactions.*

T. P. Colclough, *A Study of the Reactions of the Basic Open-Hearth Furnace.*

J. H. Whiteley, *The Function of Ferric Oxide in the Acid and Basic Open-Hearth Processes.*

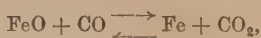
F. T. Sisco, *The Chemical Reactions in Basic Electric Process.*

W. J. Rees, *The Micro-examination of Steel-Making Refractories.*

A. L. Field, *Physico-Chemical Phenomena from Melt to Ingot.*

F. T. Sisco, *The Chemistry of Iron and Steel* (Transactions of the American Society for Steel Treating, April 1925, vol. 7, pp. 494–517). The chemistry of the acid and basic open-hearth and electric processes is described.

C. H. Desch, *The Deoxidation of Steel* (Journal of the West of Scotland Iron and Steel Institute, Jan. 1925, vol. 32, pp. 40–49). The author draws attention to some of the outstanding problems in the deoxidation of steel. According to McCance the principal cause of blowholes is the formation of carbon dioxide, which is liberated during freezing on account of its very small solubility in solid steel. The equilibrium being



any change which leads to a diminution in the quantity of dissolved oxide lessens the quantity of carbon dioxide. In very mild steel there is evidence that the sides of the blowhole weld together fairly completely in forging. On the other hand, welding in high carbon and special engineering steels either does not occur or is very imperfect, and freedom from blowholes is a matter of great importance. The removal of oxygen from steel is not easy when the concentration of dissolved oxide is large. The freedom of Swedish Bessemer steel from inclusions and its good behaviour on hardening are no doubt connected with the fact that at no stage in its manufacture is an excess of dissolved oxide introduced. The bad effects of oxygen in steel are not to be attributed to ferrous oxide alone, but that some third element must also be involved. The peculiar brittle range in Armco iron between 800° and 900° is not due to oxide, and the remarkable structure in specimens quenched within that

range appears to be connected with the presence of nitrogen, this view being confirmed by experiments now in progress in the author's laboratory. Inclusions of manganous oxide are found by Oberhoffer to have a greater effect than those of ferrous oxide alone. The paper concludes with a discussion on possible specific influence of certain agents, as distinct from their mere property of combining with oxygen to form a compound insoluble in steel.

Oxygen and the Red-Shortness of Steel (Iron Age, Nov. 20, 1924, vol. 114, pp. 1338-1340). A lengthy abstract in English of the paper by H. Monden dealing with the metallurgy of the basic open-hearth process and the influence of oxygen on the mechanical properties and red-shortness of steel, which appeared in *Stahl und Eisen*, June 7, 14, 1923, vol. 43, pp. 745-752, 782-788. This Journal, 1923, No. II. p. 433.

G. F. Comstock, *Aluminium and Titanium as Deoxidisers* (Iron Age, Dec. 4, 1924, vol. 114, pp. 1477-1479). The author describes a number of tests carried out to determine the relative values of aluminium and titanium as final deoxidisers. The investigation was confined to acid electric furnace practice. The results show that with acid electric steel heats, divided so as to eliminate the effect of accidental differences in composition or quality, the portions treated with titanium gave superior results in tensile tests, especially in ductility, as compared with similar portions treated with aluminium. The aluminium-treated steel was found to contain inclusions of alumina, more or less segregated in groups, while the titanium-treated steel contained slag inclusions which were in no case thickly segregated. The chief factor affecting the physical properties of the aluminium-treated steel was found to be the arrangement of the sulphide inclusions in curved streaks, which caused the tensile test specimens to crack before good ductility was shown. In the titanium-treated steel the sulphides were scattered irregularly in isolated globules and the microstructure was finer and more uniform.

C. H. Herty, jun., and O. S. True, *The Reaction between Manganese and Iron Sulphide* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). The reaction by which manganese sulphide is formed is $\text{Mn} + \text{FeS} = \text{MnS} + \text{Fe}$. This reaction is generally considered to be reversible, although McCance (*Journal of the Iron and Steel Institute*, 1918, No. I. p. 239) states that such is not the case. The experimental work was carried out to confirm the results of Rohl (*Iron and Steel Institute: Carnegie Research Memoirs*, 1912, vol. 4, p. 28), as to the reversibility of the reaction. The results show that manganese sulphide, even in the presence of an excess of manganese, will be converted to iron sulphide and enter the metal, the reaction, therefore, being reversible. Further, the greater the excess of manganese the lower the sulphide in the metal, regardless of whether the sulphur is originally present as MnS or as FeS.

W. Eilender, *Steel-Making Processes, with Special Reference to the Production of High Quality Steel* (*Stahl und Eisen*, Dec. 18, 1924, vol. 44, pp. 1637-1644). The author deals mainly with the question of the

deoxidation of the molten metal. It is now generally accepted that slag inclusions owe their origin to the reaction between the bath and the gases taken up during the refining process, and of all such gases oxygen is the most dangerous in this respect. The following points are emphasised: Deoxidation should be most thoroughly carried out, avoiding the use of such deoxidisers that lead to the formation of solid deoxidation products. The development of deoxidation processes by means of carbon alone under reduced pressure should be aimed at. The bath should be allowed to remain quiescent for as long as possible. The processes should involve the careful elimination of impurities, such as sulphur and phosphorus, and ready control of the temperature of the bath.

E. Houbaer, *The Complex Action of Manganese and other so-called Deoxidising Agents used in Steel Manufacture* (Revue Universelle des Mines, Nov. 15, 1924, vol. 4, Series 7, p. 217). A critical abstract of the paper read by F. Giolitti (Journal of the Iron and Steel Institute, 1923, No. II. pp. 35), and of the discussion to which it gave rise.

E. G. Smith, *Use of Limestone in Acid Open-Hearth Furnace* (Foundry Trade Journal, Oct. 30, 1924, vol. 30, pp. 380).

B. Bogitch, *The Sulphurisation and Desulphurisation of Metals by Cinder or Basic Slags* (Revue de Métallurgie, Nov. 1924, vol. 21, pp. 682-685). Sulphurisation is employed chiefly in the preparation and treatment of matter in various processes. It is only that portion of the article which relates to desulphurisation which bears on the metallurgy of iron and steel. In such instances the cinder or slag must contain lime, either in the free state or combined with sulphur. The reaction is represented by the formula:



which further indicates the necessity for the presence of carbon. If it be absent the calcium sulphide will decompose and its sulphur recombine with the metal. A state of equilibrium exists therefore as regards the distribution of the sulphur between the metal and the slag. What the proportional distribution is, is not known, and certain experiments have therefore been undertaken with the object of ascertaining what really takes place. A metal high in sulphur was found to be rapidly desulphurised by powdered lime, whereas desulphurisation took place very slowly when but little sulphur was present. Calcium fluoride or chloride, as proposed by Saniter, accelerates the reactions. In the solid metal sulphur can be reduced by heating with carbon, and when anthracite was used 0.028 per cent. of sulphur was removed by such means.

B. Bogitch, *Desulphurisation of Metals by Basic Slag* (Iron and Coal Trades Review, Apr. 17, 1925, vol. 110, p. 625). An English abstract of the above paper.

C. H. Herty, jun., A. R. Belyea, E. H. Burkart, and C. C. Miller, *Some Factors affecting the Elimination of Sulphur in the Basic Open-Hearth Process* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). The authors present a detailed

report covering the relations in open-hearth reactions between the sulphur in the slag and the sulphur in the bath, and the laws under which the amount in steel can be reduced most effectively. Three types of furnaces were used in the experiments; a small gas-fired furnace holding about 4 lbs., a 100 lbs. Booth electric furnace, and a 100-ton open-hearth furnace. The paper is replete with mathematical calculations covering the various phases of the experiments. In considering the application of the experimental results to practical operation it is necessary to consider two points: (1) How much sulphur may be removed from the bath in the usual time of working a heat by a fuel gas free from sulphur; (2) will the saving obtained by desulphurising the bath with a clean gas be offset by the cost of cleaning the gas and by any other disadvantages incurred?

The following conclusions are arrived at: A direct ratio exists between the concentration of sulphur dioxide over the bath and the amount of sulphur picked up by the scrap during melting. A direct ratio also exists between the concentration of sulphur dioxide over the bath and the concentration of sulphur in a slag containing lime, when sufficient time has been allowed for equilibrium to be established. The ratio between the gas and the oxide formed on melting is

$$\frac{\text{vol. per cent. SO}_2 \text{ in gas}}{\text{per cent. S in oxide}} = \text{about } 0.90.$$

The ratio between the gas and slags containing lime is

$$\frac{\text{vol. per cent. SO}_2 \text{ in gas}}{\text{per cent. S in slag}} = 0.270.$$

The rates of sulphur absorption and of desulphurisation are equal, and have a numerical value of about 0.004 lb. of sulphur absorbed or lost per minute per square foot of slag-gas surface per unit concentration (per cent.) difference between the sulphur in the slag and the sulphur that would be in equilibrium with the gas over the slag. The use of a gas free from sulphur will allow a much higher percentage of sulphur in the charge of an open-hearth furnace, and will prevent the loss of time due to high-sulphur heats encountered in present-day practice. Sulphur-free gas will be economical under certain conditions as it will allow a higher sulphur and, therefore, cheaper pig iron to be used, and there will be no time lost on high-sulphur heats. The economy in using sulphur-free coke-oven gas is much greater than in using sulphur-free producer-gas, on account of the larger volumes of producer-gas which must be purified.

There is a direct loss in using sulphur-free producer-gas unless the time lost on high-sulphur heats is above 1.5 per cent. of the total working time. Clean coke-oven gas is economical under almost all conditions. The exceptions are when low-sulphur charges are being worked and the consideration of time lost on high-sulphur does not arise. When burning any fuel in the open-hearth, the waste gases should

not exceed 0.035 per cent. sulphur dioxide if sulphur absorption is to be avoided. When coke-oven gas and tar are burned together, the coke-oven gas should be cleaned to 125–135 grammes of sulphur per 100 cubic foot of gas if high-sulphur heats are to be avoided.

K. G. Troubine, *Manufacture of Open-Hearth Steel with Carbonaceous Materials* (Revue de Métallurgie, Extraits, June 1924, vol. 21, pp. 303–308). A detailed report is given of the operations of three Russian steel plants using the Leopold Pszczolka process for the manufacture of open-hearth steel. The process consists essentially in replacing the pig iron in the charge by carbonaceous materials, such as graphite, anthracite, coal, coke, lignite, or dry wood. It is concluded that the process is not advantageous from an economic standpoint, but it was of importance in Russia during the war owing to the shortage of pig iron.

H. Steinhaus, *Preparatory Work in the Manufacture of High Quality Steel* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1743–1745). Economic considerations in the manufacture of high quality steel are mainly dealt with.

J. Bowron, *Steel-Making in Alabama* (Mining and Metallurgy, Nov. 1924, vol. 5, pp. 522–525). The author traces the development of steel manufacture of the Birmingham district of Alabama.

Specifications for Iron and Steel Scrap, and Scrap Handling.—E. J. Lowry, *Iron and Steel Scrap* (Paper read before the American Iron and Steel Institute, Oct. 25, 1924). The paper sets forth in detail the evils attendant upon the indiscriminate use of scrap and advocates a new and more concrete specification covering the different grades of scrap utilised in the steel industry of the United States, since the specifications now in force no longer meet present-day requirements. Sulphur is introduced into the bath by the use of scrap such as boiler tubes having lime and sulphate incrustations, or motor car tyre rims to which parts of the rubber tyre fabric still adheres. Steel scrap containing chromium, nickel, copper, and other alloys leads to increased cost in working the heat, or produces red-shortness, or, again, gives a poor finishing surface to the steel produced. Scrap which is heavily rusted is not an economical material for use in melting practice; dirty scrap also adds to manufacturing costs. Galvanised or tinned scrap is another source of trouble to the steel maker. The blast-furnace is an important consumer of some grades of scrap, and the tonnage used is on the increase. The electric furnace has also proved a source for the consumption of various special grades of scrap. The tonnage of steel produced from such units has increased enormously during the past twelve years. One of the most interesting scrap-consuming developments of the past few years is the Kranz process for the production of malleable iron castings. The largest proportion of the scrap used proceeds from the mills themselves. This scrap does not find its way to the market, but is remelted by the producer. The total annual tonnage of scrap produced in the United States amounts to about 25,000,000 tons. Of this amount approximately

12,000,000 tons, consisting of railroad, industrial, motor-car, and country scrap, and including about 1,100,000 tons of imported scrap, constitute the quantity which finds its way to the market. The remaining tonnage remains within the confines of the steel mills for remelting purposes.

W. V. Phillips, *Iron and Steel Scrap* (Paper read before the American Iron and Steel Institute, Oct. 1924). The marketing of scrap is discussed from the dealer's point of view.

New Scrap Specifications (Iron Age, Jan. 8, 1925, vol. 115, pp. 137, 175-176). Particulars are given of the new iron and steel scrap specifications, prepared by the National Association of Purchasing Agents of the United States.

Using Briquetted Chips as Furnace-Scrap (Iron Age, Dec. 11, 1924, vol. 114, pp. 1537-1538). Particulars are given of the method of handling and briquetting metal borings and turnings for use as scrap in the electric furnace at the plant of the Timkin Roller Bearing Co., Canton, Ohio. The turning machines are placed in line and straddle a tunnel in the centre of which runs an electric monorail trolley from which a magnet is suspended. The chips and cutting compound drop into the tunnel, the former collecting on the floor, and the compound running off into a drain to be recirculated to the turning machines. The trolley and magnet traverses the tunnel, automatically reversing at each end. Travelling forward the magnet is energised and picks up the accumulated chips from the floor. Arriving at the end of the tunnel, the current is automatically reversed, dropping the chips into a chute. On its return journey the magnet is neutral. The chips drop out of the chute into the path of a strong air current produced by a fan and are blown through a 12-inch pipe a distance of 360 feet to the storage pile at the briquetting machine.

Electric Scrap-Baling (Blast-Furnace and Steel Plant, Oct. 1924, vol. 12, p. 450). A scrap-baling press in use at a German steelworks is illustrated. It is provided with a vertical and horizontal stamping punch, both driven by electric motors, and can deal with very bulky scrap, which is compressed first downwards and then sideways, causing the scrap to interlace thoroughly until it forms a bundle which will withstand rough handling during storing and handling. According to the size of bundle the output varies between 20 and 70 tons per eight-hour shift.

Electric Steel Furnace Practice.—J. A. Seede, *Horizontal Ring Induction Furnaces* (Iron Age, Nov. 13, 1924, vol. 114, pp. 1281-1282). The induction and arc types of electric furnaces for the melting of metals are compared, and the advantages of the induction furnace are pointed out. It is better to develop heat in the metal or below it than at the top, and the continuous positive circulation ensures thorough mixing and prevents segregation. The self-attraction results in pinch effect when the current is too high, and repulsion between the metal and exciting coil

is an active agent in freeing the metal from gas and slag. The induction furnace process means extra handling of the molten metal, but the metal will obviously be of a better grade. The largest installation of a horizontal ring-type induction furnace is at the plant of the Allegheny Steel Co., Brackenridge, Pennsylvania, with a capacity of 6 tons (6000 kilogrammes). The furnace is rated at 800 kilowatts and is operated from a motor generator set taking power through a transformer from a 25,000 volt 3-phase, 60-cycle circuit.

H. Illies, *The Rennerfeldt Electric Furnace* (Blast-Furnace and Steel Plant, Feb. 1925, vol. 13, pp. 70-72). A short description is given of the Rennerfeldt furnace, showing a new arrangement of electrodes, namely, two horizontal and one vertical roof electrode. The arc can be adjusted to any height within the furnace.

F. Farup, W. Fleischer, and E. Holtan, *The Electrical Conductivity of Molten Slags* (Chimie et Industrie, July 1924, vol. 12, pp. 11-15). After pointing out the importance of determining the electrical conductivity of slags when electro-metallurgical methods are involved, reference is made to the work of C. Doelter, and of F. M. Jaeger and B. Kapma, on tungstates and molybdates of sodium. The research described bears on the binary silica-lime slags and on the ternary silica-lime-alumina slags. The methods employed gave accurate results only below temperatures of 1550° to 1600° C. The slags were prepared artificially from pure rock crystal, pure carbonate of calcium, and pure alumina. A description of the apparatus and methods employed is given, and a number of diagrams recording the results are appended. Graphite electrodes were used in each case and renewed for each experiment. Conductivity increases greatly with increased temperature, particularly in the vicinity of the melting points. The increase in the conductivity varies, however, considerably, according to the composition of the slags, and is retarded in proportion as the amounts of silica or alumina increase. The viscosity and the conductivity appear to be intimately related. The binary slag containing 35 per cent. of lime and 65 per cent. of silica showed the highest electrical conductivity encountered during the experiments. The cooling curves in the case of ternary slags indicate that crystallisation does not occur, but that the slags, on solidifying, behave like glass.

C. Hering, *Electromagnetic Forces Available in Electric Furnaces* (Paper read before the American Electrochemical Society, Apr. 1925). The author discusses briefly the various mechanical forces produced by current-carrying conductors. The quantitative value of the longitudinal or "stretching force" is presented for the first time, and formulæ for the calculation of this value are discussed.

H. S. Primrose, *Manufacture and Uses of Stainless Iron* (Paper read before the Manchester Association of Engineers: Foundry Trade Journal, Jan. 15, 1925, vol. 31, pp. 56-59). The production of mild stainless steel by the Hamilton-Evans process, its properties and workability, are dealt with. Mild steel scrap is melted in an electric furnace. The

slag is then poured off, and a slag known as the reception slag is introduced on to the bath. When this slag is in a suitable condition, chrome ore intimately mixed with ferro-silicon is added. The entire body of the ore with all its refractory components is fused, and the chromium oxide, iron oxide, and manganese oxide are reduced by the action of the silicon in the ferro-silicon. The chromium and other metals so formed descend into the molten metal, while the other components of the ore are retained in the slag. The silica resulting from the oxidation of the silicon combines with the lime in the slag, and the basic lining is thus protected from excessive corrosion, while the resulting slag, after reduction has taken place, acts as a refining agent for the molten metal. Mild stainless steel contains from 11 to 14 per cent. of chromium, 0.1 per cent. of carbon and under, the other constituents being all more or less in normal percentages. In addition to its corrosion-resisting properties, it resists scaling to a remarkable degree up to about 825° C. It also retains its strength at high temperatures much more than ordinary mild steel. The most suitable hot-rolling temperature for this material is from 1050° to 1100° C., and it is essential that for rolling and forging the material should be brought up slowly to about 900° C., and then slightly quicker to the rolling and forging temperature. It should be allowed to soak for a long enough period to ensure a uniform temperature through and through. For forging, it should be worked quickly and with rapid blows at temperatures of from 1150° to 900° C. Below 900° C. to 850° C. it is not so easily deformed, and if any heavy work is put on the material after it has fallen below these temperatures it is apt to be badly stressed or burst. The critical range of mild stainless steel runs from about 865° C. to 965° C., which is very wide, due to the slowing of the rate of carbon diffusion by the presence of chromium in the steel. The material will cold-roll, cold-draw, and deep-draw or press very well, but owing to the percentage of chromium in the metal, the depth of each draw, when the steel is being deep-pressed or drawn, is only about half that obtained when working on mild steel, before the material must be annealed.

J. L. M. Yardley, *Electro-Metallurgical Applications* (Blast-Furnace and Steel Plant, Dec. 1924, vol. 12, pp. 532-535; Jan. 1925, vol. 13, pp. 20-25). A general consideration of practice and economy in the utilisation of electric energy for the smelting of metals.

H. B. Smith, *The Electric Furnace* (Foundry Trade Journal, Mar. 26, 1925, vol. 31, p. 264). The production of steel in a Snyder electric furnace is briefly discussed.

D. D. MacGuffie, *The Care of the Electric Steel Furnace* (Metal Industry, Oct. 31, 1924, vol. 25, pp. 429-430). A brief discussion of the chief points in the operation of the Heroult basic electric furnace.

T. S. Quinn, *Notes, Including Conversion Cost Data, on the Performance of 2-Ton Electric Steel Furnaces* (Paper read before the American Foundrymen's Association, Oct. 1924). The author presents certain data covering a period of two years' operation of two 2-ton

Heroult acid-lined furnaces, and the cost of conversion per ton of steel in the ladle by months over that period of time.

H. R. Crago and J. A. Seede, *Closer Electrode Control* (Iron Age, March 12, 1925, vol. 115, pp. 763-764). Particulars are given of a new type of automatic electrode regulator for electric arc furnaces ensuring a constant current input to the furnace.

Steel Industries in Various Countries.—*The Special Steel Industry in Germany and Austria* (Stahl und Eisen, Dec. 18, 1924, vol. 44, Supplement, 66 pp.). Illustrated descriptions are given of twenty-three steelworks in Germany and one in Austria engaged in the manufacture of special steels for many various purposes, with some account of the nature of their special products.

B. F. Castle, *Alpine-Montan. Austria's Steel Producer* (Iron Age, Feb. 5, 1925, vol. 115, pp. 404-407). Brief particulars are given of the various plants operated by the Oesterreichische Alpine-Montangesellschaft, together with particulars of outputs.

F. Giolitti, *The Cogne-Girod Electric Steelworks, Aosta* (Iron and Coal Trades Review, Apr. 24, 1925, vol. 110, pp. 663-666). The lay-out and equipment of this plant for the production of special steel are described and illustrated.

Steel Capacity in the United States (Iron Age, Jan. 1, 1925, vol. 115, pp. 9-18). Tables are given showing the annual productive capacity of steel ingots and the principal forms of rolled iron and steel in the United States on Dec. 31, 1922. The tables are subdivided into fourteen producing districts and give detailed figures for every steelworks or rolling-mill in existence in the country at the end of 1922. The total ingot capacity is put at 55,500,000 tons.

The Brazilian Steel Industry (Giesserei Zeitung, Oct. 15, 1924, vol. 21, p. 443). The first electric steel foundry in Brazil has been established at Ribeirao Preto by the Companhia Electro-Metallurgica Brasileira. The plant consists of two Swedish electric smelting furnaces, two 6-ton converters, one 6-ton Ludlum electric steel furnace, one 16-inch rolling-mill, and one 10-inch rolling mill. The ores are obtained from the Morro do Ferro mines, about seventy-five miles distant, and are of very high-grade quality, containing 65 to 67 per cent. iron—that is, they are nearly pure ferric oxide. Charcoal is used as fuel in the smelting furnaces.

II.—CASTING AND TREATMENT OF INGOTS.

Casting Temperature of Steel.—H. D. Hibbard, *Finishing Melting Temperatures of Simple Ingot Steels* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). For the proper consideration of casting temperatures, all steels should be divided into three classes: Killed steels, which settle in freezing and

contain no gas holes : partly killed steels, which contain some gas holes that are more or less harmful ; and effervescing steels, which evolve gas freely in the moulds. Steels of these classes behave differently from each other, with variations in casting temperature. The effect of temperature on crystallisation, and particularly on the formation of "chill" dendrites in the outer metal, is most important. The hotter the steel as it enters the mould, the longer time these dendrites will be in forming, the larger they will be, and the more completely the freezing metal in forming them will reject the non-ferrous substances it contains, causing them to collect along the grain boundaries, where they form relatively weak interfacial layers. The assumed temperatures for finishing and casting simple steels with carbon ranging from 0.10 to 1.50 per cent. are tabulated. In killed steels the ill effect, if any, of a too high casting heat is pronounced ingotism, manifested through the behaviour of the carbide of iron as well as the solid and liquid impurities, and particularly their concentration along the grain boundaries. Crucible steel, well killed, may be cast exceedingly hot without damage to its quality. The ill effects of a too high casting temperature on partly killed steels may arise from the action of the high heat on one or more of the solid, liquid, or gaseous impurities contained. Such steels, as a rule, are not well made, but they vary much in that respect. When making effervescing steel, the casting temperature, through its effect on the gases, is the condition that determines the quality and hence the usefulness of the product. It affects in part the activity of the boil of the bath, which, however, depends also on the supply of oxygen that reaches the metal. It also affects the rate of effervescence in the moulds. The main thing is that the ingot shall not contain skin holes.

Gases in Steel.—N. Parravano and A. Scortecchi, *Gases and Oxygen in Steels* (Annali di Chimica Applicata, 1924, vol. 14, pp. 3–17 ; Revue de Métallurgie, Mémoires, June 1924, vol. 21, pp. 340–341). Tests were made by exhausting samples of open-hearth and of electric-furnace steel at 1000° C. *in vacuo*. The stable form for oxygen in steel is, at ordinary temperatures, oxide, and the volume of gaseous oxygen present is a function of the amount and distribution of the oxides present. Ledebur's method gives low results owing to the reduction of oxides other than those of iron, such, for example, as oxide of manganese, or of oxygen from silicates. There is no evidence that aluminium or silicon render the gaseous oxides more soluble.

P. Klinger, *An Investigation of the Gases Evolved on the Teeming and Solidification of Steel* (Kruppsche Monatshefte, Jan. 1925, vol. 6, pp. 11–18). Ten heats of steel were examined during teeming and solidifying, as to the nature of the gases given off. The gas mixture consisted of carbon monoxide, hydrogen, nitrogen, and carbon dioxide. During effervescence carbon monoxide was the most abundant, but from quiescent steel hydrogen was principally given off.

A. G. Lobley and C. L. Betts, *The Influence of Gases at High*

Temperatures upon Iron, with Special Reference to the Formation of Blow-holes (Paper read before the Iron and Steel Institute, May 1925, this Journal, p. 215).

Life of Ingot Moulds.—J. H. Hruska, *Iron and Other Metals for Ingot Moulds* (Iron Age, Jan. 29, 1925, vol. 115, pp. 341–342). The author discusses the effect of molten and solidifying steel on the life of ingot moulds. A mould must resist not only the destructive action by physical causes, such as erosion, but also the different thermochemical actions of the metal to which it is exposed, as, for example, high temperature corrosion. The alternate expansion and contraction of the moulds causes strains, which can be relieved only by careful annealing. A mould in daily use should be annealed at least once in two to four weeks; large moulds for 25 to 120 ton ingots should be treated when convenient—for instance, after fifteen to twenty heats. Proper care must be taken not only in the design of the ingot mould, but especially in the selection of the iron used. Iron of a medium soft character, low in phosphorus and sulphur, is found to give the best service. The use of steel for ingot moulds has given excellent results. Moulds having an inside of steel and an outside of Bessemer pig have been tried, but did not give such good results. Moulds made of iron with an addition of ferro-chrome showed a higher strength, hardness, and uniformity. The most important change, however, was in the finer size and more resistive shape of graphite, thus giving longer life to the moulds. Various analyses of ingot mould metal recommended by different authorities are tabulated.

Electrically-Heated Soaking Pits.—T. F. Baily, *Ingot Soaking Pits Heated Electrically* (Paper read before the Association of Iron and Steel Electrical Engineers: Iron Age, Feb. 26, 1925, vol. 115, pp. 617–618; Blast-Furnace and Steel Plant, Mar. 1925, vol. 13, pp. 138–140). The advantages of the electrically-heated soaking pit are discussed. The operation of an electric pit at the plant of the Donner Steel Co., Buffalo, has demonstrated that the quality of heating is uniformly better, due to accurate control of temperature. There is also less loss of metal due to formation of scale, and the cutting of the ingot as in the case of sharp gas flames is eliminated. The peak power demand on the mills is reduced, as is also the number of kilowatt-hours required for rolling. There is also a saving of space over gas-fired pits, making it possible to install twice as many pits in a given space. Taking into consideration the saving in scale and the usual cost of steel mill power, the cost of heating is actually less than by any other means, provided the ingots can be charged into the pits at such temperatures as are now common in steel mill practice.

FORGING AND ROLLING-MILL PRACTICE.

Forging Practice.—L. Aitchison, *Laps—Their Production and Prevention* (Lecture before Association of Drop Forgers and Stampers, Birmingham, Mar. 26, 1924; Forging, Stamping, Heat-Treating, Mar. 1925, vol. 11, pp. 78–80). A discussion of defects likely to occur in drop-forging practice, such as laps, folds, galls, and cold shuts, and methods of avoiding them.

K. Honda, *On the Forging Temperature of Steels* (Science Reports of the Tôhoku Imperial University, Oct. 1924, vol. 13, pp. 21–25; see also this Journal, 1924, No. I. p. 313).

A. Portevin, *Internal Strains during Forging and Annealing after Forging* (Revue de Métallurgie, Dec. 1924, vol. 21, pp. 729–733). A challenge of the popular view that annealing removes internal strain, the effect of the operation being ascribed to the chemical homogeneisation of the grain which results from prolonged heating. Experiments in which the annealing times varied from 1 hour to 20 hours, but the temperature remained constant at 900° C., were carried out. The conclusions recorded are: (1) Strains due to forging at the working temperatures ordinarily employed are insignificant, or even lacking. (2) The effect of annealing, when it occurs, is not to be attributed to the removal of strains, but to chemical homogeneisation. (3) Prolonged annealing after forging leads to a coarser structure which it is necessary, in the subsequent heat treatment, to destroy.

B. Brett, *Drop Forging* (Paper read before the Institution of Production Engineers: Engineering Production, Nov. 1924, vol. 7, pp. 337–340). Recent developments in drop-forging practice are described.

The Production of Heavy Forging (Mechanical Engineering, May 1924, vol. 46, pp. 241–247, 307). Describes practice in the United States in the production of large forgings.

G. Neumann, *Investigation of a Regenerative Continuous Heating Furnace* (Stahl und Eisen, Dec. 11, 1924, vol. 44, pp. 1611–1619). The investigation was carried out with the object of determining the efficiency of a blast-furnace gas-fired continuous billet-heating furnace, and data were obtained as to loss due to oxidation, and to the use of water-cooled rails. Defects in the design of the furnace led to a deficiency in the air supply and the irregular working of the gas and air chambers. The efficiency of the furnace was 28·7 per cent., and the consumption of heat units contained in the gas was 710 calories per kilogramme of charge. More modern furnaces show a consumption of 400 to 450 calories per kilogramme, corresponding to a coal consumption of 6 per

cent., which represents good economy, and one which is attainable in furnaces with direct firing or fired with producer-gas.

Rolling-Mill Equipment and Practice.—T. W. Hand, *Progress in British Rolling-Mill Practice* (Paper read before the Iron and Steel Institute, May 1925, this Journal, p. 43).

L. D. Whitehead, *The Continuous Rolling-Mill* (Paper read before the Staffordshire Iron and Steel Institute, Jan. 31, 1925; Iron and Coal Trades Review, Feb. 6, 13, 1925, vol. 110, pp. 211–213, 252–255). This paper gives a brief history of the origin of continuous rolling, its gradual development as illustrated by a description of typical continuous and semi-continuous mills, the author's own experience in operating mills of this type, and, finally, consideration of the question as to how far the conditions in this country will permit the application of the system.

In general practice the continuous process is not used for cogging and blooming, but at the Gary Works in Illinois there is a rail mill in which the ingot is actually continuously clogged. In billet and sheet-bar mills the continuous process is without a rival, and its great development in the United States hinges on the invention of the flying shears which enable a $1\frac{1}{2}$ -inch billet, 700 feet long, to be cut into accurate lengths as quickly as the mill can produce it. The tendency for the first thirty years of continuous rolling in rod mills was to operate on the straight-continuous principle without a gap from end to end. A decided improvement was effected when the mill was broken up into two sections, and the Morgan Construction Company greatly enhanced this advantage by the invention of the flying shears, which they inserted after the sixth-stand rolls. By this means 6 to 8 inches of the leading end was cut off, and a clean warm end presented to the finishing mill. This type of rod mill has been a great success; its capital cost was reasonable and it was most compact. It, however, required considerable skill on the part of the roller and his staff to maintain a satisfactory output consistent with a good finish. To get over this difficulty the Morgan Construction Company, in their latest designs, have split up the mill into four sections. This mill is almost identical with the straight-continuous mill, up to No. 10 stand, and has the flying shears inserted after No. 6 stand. From No. 10 the rods are looped 180° , by means of a repeater, into No. 11, and pass on continuously into No. 12, where they are again looped through a repeater into No. 13 and pass on through Nos. 14, 15, and 16 continuously. This method of rolling makes the mill very much more flexible, and the accuracy of finish is certainly better than in the straight-continuous mill.

Merchant bar mills are almost without exception of the semi-continuous type, that is to say, the use of straight-continuous rolling is confined to the roughing. The reason of this is that merchant bar mills have to cover a wide variation in sections which it would be impossible, except within a narrow range of sizes, to produce continuously with the accuracy required by the trade. As is well known, the maximum

reduction possible in each pass varies considerably in the production of rounds, squares, flats, and other sections, and it is not possible, except by driving each stand of rolls separately, to fit in these variations in reduction with a fixed range of speeds in a mill of the straight-continuous type. The author describes the Morgan semi-continuous bar, rod, and hoop mill in operation at the Tredegar Works, and the continuous hoop and strip mill at the Newport works.

Odier, *Electrically-driven Reversing Rolling-Mills at the Angleur Steel Works* (Bulletin, Association des Ingenieurs Electriciens, Liège, June 1924, vol. 2, Series 7, pp. 206-235). A detailed description is given of a combined blooming and finishing reversing mill for rolling rails. The mill is driven by a single motor controlled by two Ilgner fly-wheel sets.

K. Raabe, *Reconstruction of the Wire Rod Rolling-Mills at Düsseldorf* (Stahl und Eisen, Jan. 8, 1925, vol. 45, pp. 41-44). The extensive plant of the Düsseldorf wire manufacturers was no longer able to meet modern requirements, the roll passes being too few and the requisite labour too high. Additions and alterations have been carried out with the greatest economy, and the output of the mills has been increased by 30 to 40 per cent. The new lay-out is illustrated and described.

A New Sheet-Rolling Mill in Roumania (Stahl und Eisen, Nov. 20, 1924, vol. 44, pp. 1491-1494). An illustrated description of a sheet rolling-mill newly installed at a factory at Galatz, this being the first rolling-mill to be put down in Roumania. The mill is driven by a Güldner-Diesel motor with four cylinders, running at 150 revolutions per minute and developing a nominal horse-power of 600 h.p. The pistons are water-cooled. The mill rolls sheets of 23×33 inches with a thickness of 0.23 millimetre.

W. H. Bailey, *Blooming Mills and Blooming-Mill Practice* (Paper read before the American Iron and Steel Institute, May 1925). The author describes a number of blooming-mill installations in America, and gives a series of charts illustrating in graphic and tabular form examples of blooming-mill practice.

F. L. Prentiss, *New Sheet Bar and Hot-Strip Mills* (Iron Age, Oct. 20, 1924, vol. 114, pp. 1141-1146). The equipment of the sheet bar and hot-strip mills of the Otis Steel Co., Cleveland, is described and illustrated. The strip-mill is electrically driven, and is stated to be the first strip-mill to be built that is strictly continuous in operation.

G. F. Tegan, *First Units of Gary Tube Company* (Iron Age, Jan. 1, 1925, vol. 115, pp. 39-41). A description of the lay-out of the new mills of the Gary Tube Co., Chicago, a subsidiary of the National Tube Co., for the production of lap-welded and butt-welded pipe.

J. D. Knox, *Enlarges Semi-finishing Capacity* (Iron Trade Review, Nov. 27, Dec. 4, 1924, vol. 75, pp. 1431-1433, 1493-1496, 1500). The new rolling-mill equipment of the United Alloy Steel Corporation, Canton, Ohio, is described and illustrated.

J. D. Knox, *Dispelling Drudgery in the Hot Mill* (Iron Trade Review, 1925—i,

Feb. 19, 1925, vol. 76, pp. 503-506, 543). Illustrated particulars are given of a table type of mechanical matching and doubling machine and an automatic machine for feeding the plates into the tinning machines in use in American tinplate mills.

New Double Drive for a Reversing Two-High Rolling-Mill (Iron and Coal Trades Review, Mar. 6, 1925, vol. 110, pp. 385-386). In the method of driving described the pinions are dispensed with and each roll is individually driven by a motor of half the total power. By raising the motor attached to the top roll so that its centre is in line with the centre of the roll in its bottom position, the angle of obliquity of the driving spindle is no greater than with the normal method of driving. An account is also included of tests of this new form of drive carried out by the English Electric Company. The tests were carried out on a three-stand mill, and in spite of the additional back-lash owing to the number of coupling boxes, a perfectly satisfactory drive was obtained.

Gear Drive for Steel Mills (Iron and Coal Trades Review, Feb. 13, 1925, vol. 110, p. 269). An illustrated description is given of a gear drive for sheet mills at present being built for installation in this country. It is designed to transmit frequent peak loads up to 10,000 h.p. at 34 r.p.m. of the mill shaft, and is capable of transmitting 15,000 h.p. as a momentary peak load.

L. Rothera, *Electrical Developments in Rolling-Mill Work* (Proceedings of the Cleveland Institution of Engineers, Session 1924-25, No. 3, pp. 83-116). The author outlines the trend of progress in the electric driving of rolling-mills. Several new types of mills have recently been introduced, including an electrically driven three-high reversing plate mill. The driving of top and bottom rolls by means of separate motors and the use of roller bearings for mill trains are discussed.

Electrification of a 10-inch Rolling-Mill (Iron and Coal Trades Review, Apr. 3, 1925, vol. 110, p. 550). The general arrangement of the electric drive for the 10-inch section mill at the works of the London Works Iron Co., Oldbury, is described and illustrated.

J. S. Erichson, *Electric Rolling-Mill Drive* (Electric Journal, Sept. 1924, vol. 21, pp. 403-407). The article describes the conversion of a 22-inch bar mill and a 24-inch section mill of the Phoenix Iron Company, Phoenixville, Pennsylvania, from steam to electric drive. The production of the mills has been considerably increased and the life of the rolls is practically doubled. The power consumption is about 48 kilowatt-hours per ton of steel rolled.

Chain-Driven Cold Rolls (Iron and Coal Trades Review, Apr. 10, 1925, vol. 110, p. 580). Particulars are given of the application of a chain drive to cold rolls at the works of the Grovesend Steel and Tinplate Co., Ltd.

J. D. Knox, *Loose Rolling Gains Favour among Sheetmakers* (Iron Trade Review, Dec. 25, 1924, vol. 75, pp. 1706-1711, 1722). Illustrated particulars are given of the methods and plant of the Youngstown Sheet and Tube Co., for the production of high-grade automobile sheets.

The sheets are loose rolled in order to meet the demands of the consumers for sheets of high finish. In this method the sheet bars are roughened down to within about 60 per cent. of the length called for in the specifications. The partially rolled sheets are then pickled and matched in packs of three. Each middle sheet is dipped in a solution of charcoal and water, maintained at a suitable temperature by steam. The fine particles of charcoal prevent the sheets from sticking when the pack is finished off. After reheating, the pack passes through the finishing mill. At various stages of reduction compressed air is directed on the pack to remove any foreign substance that might be rolled into the steel. The sheet is then annealed, again pickled, and cold rolled.

Electrically Produced Boiler Plate (Electrician, Nov. 28, 1924, vol. 93, pp. 614-615). Illustrated particulars are given of the electrical driving equipment for the three-high plate mill at the Clydebridge Works of David Colville & Sons. The Ilgner system is used.

Casedamont, *Study of Power Requirements in a Modern Iron and Steel Plant* (Chimie et Industrie, May 1924, pp. 224-229). The author has made a detailed analysis of the production, distribution, and utilisation of power in iron and steel works.

W. Tafel and H. Weiss, *Design of Roll Passes* (Stahl und Eisen, Oct. 9, 1924, vol. 44, pp. 1243-1245). Calculations are given for determining the size of roll-passes, so as to obtain a given reduction of cross-section with the corresponding elongation of the material.

W. Tafel and H. Sedlacek, *Spread in Rolling* (Stahl und Eisen, Feb. 5, 1925, vol. 45, pp. 190-193; Iron Trade Review, Mar. 12, 1925, vol. 76, pp. 693-695).

G. Fox, *Electric Heating of Sheet and Tin Mill Rolls* (Blast-Furnace and Steel Plant, Nov. 1924, vol. 12, pp. 493-496). Electric preheating of rolls of sheet and tinplate mills is a new development, and is said to have proved superior to any previously tried methods for preheating rolls. The device consists of two frames, each carrying two flexible cylindrical sectors, on the internal surface of which the heating elements are fitted. The frames are clamped over the rolls in place in their housings. The heaters are made in sizes suited to 28-inch and 30-inch rolls respectively, and will fit rolls of slightly larger or smaller diameters than the standard. The uniformity of heating is excellent, and the heating can be performed either slowly or rapidly, as may be desired.

Repeater for Transferring Hot Strip on Edge (Iron and Coal Trades Review, Oct. 17, 1924, vol. 109, p. 623). A brief illustrated description is given of the Flynn-type repeater for the continuous passage of hot-rolled steel strip between two mills not in line. Various transfer conditions can be accomplished with this repeater, including the passage of the strip from a flat mill to an edging mill, from an edging mill to a flat mill, and from one flat mill to another.

German Practice in Automatic Cooling Beds (Iron and Coal Trade Review, Oct. 17, 1924, vol. 109, p. 632). An English abstract of a paper by H. Hilterhaus, discussing the modern trend in the design of automatic

cooling beds, which appeared in *Stahl und Eisen*, July 3, 1924, vol. 44, pp. 777-784.

New Type of Mechanical Hot Bed (*Iron Age*, Oct. 16, 1924, vol. 114, pp. 990-991). An illustrated description is given of a new type of mechanically operated hot bed for handling billets, bars, and structural shapes. It is known as the McKee hot bed.

FURTHER TREATMENT OF IRON AND STEEL.

Cementation and Case Hardening.—I. Musatti and M. Croce, *The Influence of the Nitrogen of Nitrogenous Cementation Agents on the Cementation of Steels* (Annali de Chimica Applicata, 1924, vol. 14, pp. 18-59; Revue de Métallurgie, Mémoires, June 1924, vol. 21, p. 340). The authors have studied the influence of nitrogen by subjecting a soft steel and a nickel-chromium steel to cementation under varying conditions with a number of cementation compounds. The differences in behaviour among the various compounds were greatest in the soft steel. The amount of nitrogen introduced into steel by solid cementation materials under ordinary conditions of industrial practice is relatively small and becomes smaller as the temperature increases. The diffusion of carbon and of nitrogen into steel is a function of the time and temperature, the rate of diffusion of nitrogen being greater than that of carbon. The micrographical results under the various conditions of cementation are discussed. A study of the influence of nitrogen on the mechanical properties of steel, particularly the brittleness, is also included.

R. T. Haslam and L. E. Carlsmith, *The Cementation of Iron by Silicon* (Industrial and Engineering Chemistry, Nov. 1924, vol. 16, pp. 1110-1113). The variables affecting the siliconisation of iron are: the temperature of cementation, duration of the heat, composition of the silicon, composition of the metal, and atmosphere used in the cementation furnace. The cementations described were carried out in a carbon resistance furnace, constructed so as to permit good temperature control, and temperatures were measured by a chromel-alumel thermocouple. Polished samples of iron and steel were packed in 120-mesh ferro-silicon contained in a fireclay crucible. The furnace was brought to temperature before inserting the crucible into the chamber. The depth of penetration increases rapidly with the temperature. At temperatures from 1120° to 1200° after three hours' heating the average case thickness obtained was 0.014 inch, the maximum depth of penetration being 0.0214 inch. The most effective cement was obtained with a 76 per cent. ferro-silicon, which produced twice as much penetration as a 51 and a 97 per cent. ferro-silicon in the same time (three hours). The data at hand are insufficient to furnish an explanation of this result, but it is believed that the 76 per cent. ferro-silicon contained FeSi_2 , which, being fairly near its fusion point, had a relatively high vapour pressure, which is the requirement of a good cement. Analysis of some of the

cemented specimens showed 6 to 10 per cent. silicon in the case, the original iron containing no silicon. The atmosphere in the furnace is of secondary importance, any inert or reducing gas being satisfactory. Tests for resistance to acid corrosion show that an acid-proof case cannot be produced.

B. F. Shepherd, *The Influence of Barium Carbonate upon Wood Charcoal used for Cementation* (Transactions of the American Society for Steel Treating, Nov. 1924, vol. 6, pp. 606-614). The paper illustrates the effect of barium carbonate in intensifying the carburising properties of wood charcoal. Caron, in 1861, used a mixture of 60 parts of wood charcoal to 40 parts of barium carbonate, and this became known as the "inexhaustible cement" because of the action of the carbonate in regenerating the carburising properties of the used charcoal when exposed to the action of the atmosphere. The paper shows that the quantity of barium carbonate used in the mixture, which has been standard since 1861, does not give the best results.

A chrome-vanadium steel absorbs carbon much more readily than a simple carbon steel, and there may result a hypereutectoid zone of such a depth and carbon concentration as to be extremely harmful.

H. Rodman, *Specific Effect of Alkalies in Carburising Compounds* (Transactions of the American Society for Steel Treating, May 1925, vol. 7, pp. 635-639). The paper presents the results of certain laboratory tests made on various compositions of carburising materials. The energising effect of carbonate additions varies with the position of the alkalies or alkali earths in the periodic system. It was noted that the energising effect increases with the increase of atomic weight of alkali earth and decreases with the decrease of the atomic weight of the alkalies.

A. R. Page, *Recent Developments in Case-Hardening* (Metal Industry, Mar. 20, 27, Apr. 3, 1925, vol. 26, pp. 297-299, 321-323, 345-347). The author deals briefly with the early development and principles of the case-hardening process, and discusses modern theory and methods.

F. Brüsewitz, *Heat-Treatment of Case-Hardened Parts* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1697-1698). From the results of impact tests it is concluded that the most effectual heat treatment of case-hardened articles is to quench in oil directly on removal from the furnace, then to anneal for one hour at 600° C. and to give a final quench from 765° to 800° either in water or oil. The intermediate annealing refines the structure, and gives the highest value for notch toughness.

Heat-Treatment of Steel.—*Continuous Annealing Furnace at Bryngwyn Sheetworks* (Iron and Coal Trades Review, Mar. 6, 1925, vol. 110, p. 397). Particulars are given of the 800-ton continuous annealing furnace in operation at the Bryngwyn Sheetworks of the Grovesend Steel and Tinplate Co. Ltd., Gorseinon.

New Annealing Equipment for Strip Steel (Iron Age, Oct. 9, 1924, vol. 114, pp. 907-909). An illustrated description is given of the design

of the Fisher annealing furnace for steel strip in operation at the plant of the Worcester Pressed Steel Co., Worcester, Mass. The furnaces are oil-fired and are charged by means of a specially designed charging mule. Each furnace is equipped with two burners, oil being delivered at a pressure of about 35 lbs. per square inch by a motor-driven pump, air for atomisation being delivered at a pressure of about 14 ozs. The annealing pots are designed for a maximum load of about 18,000 lbs. of strip steel. The oil consumption is about 87 lbs. per ton of steel annealed.

W. Rohn, *Electric Annealing Furnaces* (Zeitschrift des Vereines Deutscher Ingenieure, Oct. 18, 1924, vol. 68, pp. 1101-1105). The advantages and economies obtained by the use of electric annealing furnaces as compared with those heated by fuel are considered, and the construction of the Heraeus vacuum type of furnace is described. The exclusion of oxygen is one of the principal advantages. To heat 4000 kilogrammes of iron at 800° C. for four hours, 970 kilowatt-hours are required, and if the period is prolonged to eight hours the consumption is 1072 kilowatt-hours.

A. E. White, *The Use of Electric Furnaces in Heat-Treatment* (Paper read before the American Electrochemical Society, Oct. 1924). Various types of heat-treating furnaces are compared. Examples of performance using various fuels, as well as costs of operation, are given. The author formulates recommendations for furnace design. The dimensions, temperature, difference between the heat source and the heat in the stock, distribution of heating elements, insulation, heat circulation, accuracy of temperature control, resistors, and various furnace types are considered. From all these standpoints the electric heat-treating furnace is found to be most advantageous. Appendices are included in the paper giving definitions of terms used in heat-treatment, heating values for iron at different temperatures, and heat-treatment furnace data obtained from a number of plants. A very complete bibliography of electric heat-treatment practice is also appended.

S. A. Sears, *Gas Furnaces Applied to the Steel Industry* (Lecture before Sheffield Society of Engineers and Metallurgists, Feb. 23, 1925; Engineering, Feb. 27, 1925, vol. 119, pp. 275-276).

H. O. Loebell, *Gas as a Factor in Improving Quality Standards and Lowering Production Costs of Heat-Treated Steel* (Transactions of the American Society for Steel Treating, Jan. 1924, vol. 7, pp. 107-123). The author discusses the importance of gaseous fuels in their application to the heat treatment of steel. Gaseous fuels are compared with liquid and solid fuels and electricity, and conclusions are drawn which favour gaseous fuels in preference to all other types.

J. A. Doyle, *Selections of Fuels for the Heat Treatment of Metal* (Transactions of the American Society for Steel Treating, Jan. 1924, vol. 7, pp. 101-106). The factors to be noted in the selection of a suitable fuel for heat treatment are discussed. Each form of fuel or electricity and furnace has its field of usefulness as well as its limitations.

G. Wallquist, *The Automatic Temperature Control of Furnaces* (Jernkontorets Annaler, 1925, vol. 80, pp. 111-144). Devices in use in America and England for the automatic regulation of temperature of heating and heat-treatment furnaces are illustrated and described.

W. J. Merten, *Fused Salt Baths for the Prevention of Soft Spots in Quenched High-Carbon and Carburised Steels* (Transactions of the American Society for Steel Treating, Jan. 1925, vol. 7, pp. 23-33). Ordinary quenching liquids do not rapidly dissolve the salt films which form on the steel from the sodium and potassium chloride heating bath. They seem to promote rather than prevent the formation of gas films at the surface of the steel under treatment. Vapour and salt films are poor conductors of heat, and, wherever present, they prevent drastic cooling and consequently cause irregular hardness of the steel over areas where these films occur. The use of a quenching medium consisting of 300 gallons of water, 150 lbs. of sodium chloride, 100 lbs. of lime, and 75 lbs. of sodium cyanide, solves the problem of uniformly producing a fully hardened steel when heated for hardening in fused salt baths, the resultant structure being entirely martensitic. The purification of fused salt baths composed of equal parts of sodium and potassium chlorides by the addition of boric acid and charcoal is also dealt with.

C. W. Mason, *Temper Colours* (Journal of Physical Chemistry, 1924, vol. 28, pp. 1233-1244). It is asserted that, contrary to the views of A. Mallock (this Journal, 1919, No. I. p. 674, Abstract) and others, temper colours are due to interference of light reflected from the two surfaces of a film of a compound of the metal formed on its surface. The view that the colours are due to diffraction or selective reflection does not afford an adequate explanation and is inconsistent with their behaviour. The colour is increased by a reticulated or granular structure and a moderate degree of opacity of the film.

E. J. Janitzky, *Temperature Distribution in Steel Bodies Heated to a Constant Head Potential* (Transactions of the American Society for Steel Treating, Nov. 1924, vol. 6, pp. 619-622). This is a continuation of a previous paper, *Characteristics of Heating Curves—Their Applicability for Calculating the Time Required to Reach Constant Head Temperatures* (Transactions of the American Society for Steel Treating, Feb. 1924, vol. 5, pp. 201-208; this Journal, 1924, No. I. p. 617). The contentions set forth in the former paper are extended to temperature distribution in steel bodies heated to a constant head potential.

A. Bidault des Chaumes, *Heat Treatment of Rails* (Génie Civil, Feb. 7, 1925, vol. 86, pp. 140-143). The company Forges de Chatillon, Commeny et Neuves-Maisons, has developed a process for the treatment of rails, designed to transform the pearlitic structure of the rail head into a sorbitic one to a depth of 20 to 30 millimetres. It is intended, in fact, to produce the same effect as the Sandberg process, and the method consists of an intermittent quenching of the rail head in a limited quantity of water, proportionate to the weight of the rail to be treated. The head of the rail is dipped into water and withdrawn several times,

but is not completely cooled, and the heat of the internal metal reheats the quenched part, producing a tempering effect. The results of tensile tests show that rails with 0.45 per cent. carbon are very much toughened by this method, and the tensile strength rises from 46 to 60 tons per square inch.

E. Marcotte, *The Surface Hardening of Rails* (Génie Civil, Jan. 10, 1925, vol. 86, pp. 42-44). The treatment of rails by the Sandberg process, as carried out at the Hagondange Iron and Steel Works, is described. As is well known, the structure of the rail head is rendered sorbitic to a certain depth and the formation of a martensitic structure is avoided. Comparative results are given of trials of Sandberg rails and other types of steel rails on London railways and on American railways; these show that in comparison with ordinary steel rails the life of the Sandberg rail is from 100 to 300 per cent. longer. Diagrams illustrate the difference in the amount of wear in the same period of time under similar conditions.

A. Portevin, *Experimental Research on the Variations in Volume which accompany the Heat Treatment of Explosive Shells* (Communication from the Memoirs of the French Artillery, published by the State Printing Press, Paris, 1924, pp. 5-32). The variation in capacity of shells is influenced by the heat treatment to which the steel of which they are composed is submitted. The internal capacity of such shells is affected by the temperature at which they are hardened, and, it is important to note, by the temperature gradient between the inside and the outside of the shell when undergoing hardening. Apart from the capacity variation, any considerable difference between the temperature of the inner and outer walls leads to very severe and destructive strains in the metal. The phenomena involve what is described as the anisothermy of the mass, and the resulting unequal rates of cooling. Repeated heat treatment may have a cumulative effect. Thus the deformation which rectangular blocks of steel undergo on repeated heat treatment may have the effect of causing the rectilinear edges to become curved. The internal capacity of a shell may vary by as much as 2.5 to 5.0 per cent., a fact that requires to be borne in mind during subsequent machining operations. No fixed coefficient can be derived from the investigations undertaken, and each instance has to be dealt with individually. One practical application of the research is that shells which have been found to be unduly heavy may be rectified by proper heat treatment, and thus rendered serviceable instead of becoming discard.

H. B. Knowlton, *Facts and Principles concerning Steel and Heat Treatment* (Transactions of the American Society for Steel Treating, Mar. 1925, vol. 7, pp. 378-405). The paper discusses the heat treatment of wrought iron, cast iron, and steel, and the methods of testing the physical properties of these materials. The tensile, impact, and hardness tests are discussed in detail. The hardening of steels and the changes taking place in steel during heating and quenching are also dealt with.

C. H. Fulton, H. M. Henton, and J. H. Knapp, *Heat Treating—Its Principles and Applications* (Iron Trade Review, Sept. 25, Oct. 9, Oct. 23, 1924, vol. 75, pp. 807–809, 939–941, 1087–1089).

S. N. Brayshaw, *The Hardening of Carbon Tool Steel* (Paper read before the Institution of Production Engineers: Engineering Production, Apr. 1925, vol. 8, pp. 99–104; Engineering, Mar. 27, 1925, vol. 119, p. 382). The author describes experiments on the heat treatment of carbon tool steel. It is maintained that the best results obtainable depend not so much upon the final hardening process as upon the previous annealing or heat treatment.

J. K. Wood, *Heat Treatment of Carbon and High-Speed Steel Tools* (American Machinist, European and Colonial Edition, Jan. 10, 1925, vol. 61, pp. 791–793).

J. K. Wood, *Heat Treatment of Steel Springs* (American Machinist, European and Colonial Edition, Nov. 8, 1924, vol. 61, pp. 443–446). The general requirements of steel for springs, the composition of spring steel, and the coiling and heat treatment of helical and leaf springs are discussed.

E. L. Shaner, *Drastic Quenching imparts Surprising Properties to Bolts and Rivets* (Iron Trade Review, Apr. 2, 1925, vol. 76, pp. 871–874). Illustrated particulars are given of the system of quenching bolts in operation at an American plant. The bolts are quenched by means of a continuous stream of water instead of being dipped in the usual quenching tanks. Tests on steel quenched by this method show an increase in tensile strength.

E. F. Ross, *Heat Treating Machine Parts* (Iron Trade Review, Jan. 29, 1925, vol. 76, pp. 341–343). A description is given of the methods employed by the R. K. Le Blond Machine Tool Co., Cincinnati, for the heat treatment of machine tools, including case-hardening practice.

J. M. Watson, *The Heat Treatment of Automobile Parts* (Transactions of the American Society for Steel Treating, Dec. 1924, vol. 6, pp. 716–727). The author describes the methods and equipment used in a modern American plant for the heat treatment of automobile parts. The furnaces described are of the oil-fired, automatic conveyor type, and are specially designed to meet the requirements of the materials being treated.

V. T. Malcolm and A. Sproat, *Heat Treatment of Steel Valve Castings in the Electric Furnace* (Paper read before the American Foundrymen's Association, Oct. 1924). The authors describe the heat treatment of steel valve castings in electric furnaces of the nichrome ribbon resistor type, with automatic temperature control. Three methods of heat treatment are dealt with, and the physical properties obtained by each method are tabulated.

J. K. Wood, *The Heat Treatment of Steel Cams* (American Machinist, European and Colonial Edition, Feb. 28, 1925, vol. 62, pp. 47–49). An outline is given of the carburising and case-hardening of steel cams.

J. K. Wood, *Heat Treatment of Steel Gears* (American Machinist, European and Colonial Edition, Nov. 29, 1924, vol. 61, pp. 567-570). The requirements of gear steel and the heat treatment of gears are discussed.

J. K. Wood, *Heat Treatment of Ball and Roller Bearings* (American Machinist, European and Colonial Edition, Jan. 31, 1925, vol. 61, pp. 929-931). The chief features in the production and heat treatment of ball and roller bearings are discussed.

W. Schuurman, *Heat Treatment of Steel Castings* (Giesserei Zeitung, Feb. 1, 1925, vol. 22, pp. 68-69). The effect of a suitable heat treatment on the properties and structure of steel castings is illustrated and described.

R. S. Archer, *Some Notes on Carburised Piston Pins* (Transactions of the American Society for Steel Treating, Nov. 1924, vol. 6, pp. 615-618). A short discussion of the manufacture and heat treatment of piston pins used in the production of Liberty aircraft engines.

J. W. Bolton, *Heat Treatment of Grey Cast Iron* (Iron Age, Oct. 2, 1924, vol. 114, pp. 820-822). The author discusses very briefly the annealing and hardening of cast iron. Annealing the castings is practicable only where the strength requirements are not severe. It is shown that there is a considerable drop in strength at about 1100° F. This drop is accompanied by a radical change in structure. Hardening cast iron by quenching and drawing is a comparatively new process. Castings of small size can be hardened and the strength increased considerably by proper heat treatment. In the case of castings of heavy section it is doubtful whether the process will ever prove successful. The reason for this is that cast iron dead anneals very rapidly. Due to the difference in temperature between the outer and inner parts of the casting, the outer portion would be completely graphitised before the inner portion had reached a sufficient temperature to harden on quenching.

M. Epstein, *Heat Treating Malleable Castings* (Industrial Gas, Jan. 1925; Iron Trade Review, Feb. 5, 1925, vol. 76, pp. 383-384). A discussion of the process developed by the Bureau of Standards for the heat treatment of malleable cast iron prior to galvanising. The galvanising process has an embrittling effect on the iron. Malleable castings which are subsequently to be galvanised are heated to about 1200° F. and quenched in water. They are then galvanised in the regular manner. Specimens treated in this way show an impact value of about 140 per cent. of the original value. A description is also included of the first commercial furnace to be put into operation for this purpose (see also L. H. Marshall, *Embrittlement of Malleable Cast Iron Resulting from Heat Treatment*, U.S. Bureau of Standards, 1923, Technologic Paper, No. 245; this Journal, 1924, No. I. p. 63).

Annealing Castings Electrically (Iron Trade Review, Nov. 6, 1924, vol. 75, pp. 1225-1277). An illustrated description is given of the electric heat-treating equipment at an American foundry.

J. W. Urquhart, *Heat Treatment of Steel, with Special Reference to Production* (Machinery, Feb. 19, Mar. 12, 1925, vol. 25, pp. 648-650, 745-748).

Drawing, Cold Working, and Stamping.—*Six-Block Continuous Wire Drawing* (Iron Age, Apr. 2, 1925, vol. 115, p. 972). Particulars are given of a six-block wire-drawing machine of the Oslund type. Differential gearing is arranged to handle the blocks without undue tension or slackness in the wire.

E. A. Atkins, *Steel Wire: its Manufacture, Properties, and Uses for Welding and other Purposes* (Paper read before the Institution of Welding Engineers, Oct. 23, 1924).

S. A. Hand, *Cold-Working Steel Bars and Strips* (American Machinist, European and Colonial Edition, Dec. 13, 1924, vol. 61, pp. 637-639). The methods of cold-drawing bars and cold-rolling strip at an American plant are described and illustrated.

Spring Steel from Cold Roll Strip Mills (Iron Age, Feb. 5, 1925, vol. 115, pp. 399-402). The lay-out of the rolling-mill equipment and the methods employed for the production of cold-rolled spring steel at the plant of the Wallace Barnes Co., Springfield, Connecticut, are described and illustrated.

D. P. Cook, *Pressed Metal Engineering* (Mechanical Engineering, Mar. 1924, vol. 46, pp. 123-128). The author discusses the possibilities and limitations in the production of pressed metal parts, and shows a large number of examples of pressed steel articles for all kinds of purposes.

Chain Making.—*Wire Chain Making* (Engineer, March 6, 13, 1925, vol. 139, pp. 276-277, 292-293). An illustrated description of the method of making chains of steel and other wire. The mechanism of the chain-making machine is shown and explained.

Tube Making.—F. L. Prentiss, *Making Steel Tubes for Roller Bearings* (Iron Age, Dec. 4, 1924, vol. 114, pp. 1463-1469). A detailed description of the manufacture of alloy seamless tubes at the plant of the Timken Roller Bearing Co., Canton, Ohio.

Tubing made from Strip Stock (Machinery, Apr. 16, 1925, vol. 26, pp. 82-85). An illustrated description is given of the production of small tubes of double-wall thickness from strip.

Welding.—G. F. Tegan, *Making Large Size Hammer-Welded Pipe* (Iron Age, Nov. 13, 1924, vol. 114, pp. 1263-1268). An illustrated description of the methods employed by the National Tube Co., for the production of hammer-welded pipe. The plates are first shaped by passing through bending rolls. Five welding machines are employed for longitudinal welds and one for circumferential jointing. Water gas is used to heat the seams preparatory to welding. For longitudinal welding the pipe rests upon a carriage which can be moved backwards

and forwards over the horn which supports the anvil. The anvil is keyed to the front end of the horn, which is a 12-inch beam reaching clear of its support a sufficient distance to accommodate lengths of pipe from 21 to 31 feet. The hammer is swung from a beam directly above the anvil. Some of the hammers are air driven, while others are motor powered. After welding the pipes are annealed in furnaces of unusual size using producer-gas.

W. Spraragen, *Welding versus Riveting of Large Structures* (Paper read before the American Bureau of Welding: Iron Age, Apr. 9, 1925, vol. 115, pp. 1051, 1095-1096). The economies which might be effected by the substitution of welding for riveting in the erection of large structures are discussed.

J. B. Scholefield, *The Application of Welding to Bridgework* (Transactions of the Society of Engineers, 1924, pp. 95-108).

P. Hahn, *The Weldability of Mild Steel as Affected by Elements which Form Mixed Crystals with the Iron* (Stahl und Eisen, Jan. 1, 1925, vol. 45, pp. 7-9). Welding tests were made on an open-hearth steel with 0.1 per cent. carbon to discover the effect of additions of arsenic, copper, manganese, aluminium, and silicon. With arsenic the limit of weldability was reached at 0.10 per cent. As, and with copper at 0.9 per cent. Cu. Beyond those amounts the steel parts refused to weld. Steel with manganese up to 3.41 per cent. welded easily, and the limit of weldability was not reached at that point. Steel containing silicon over 0.3 per cent. would weld, but broke immediately on bending. The welding limit for steel with aluminium was found at 1.40 per cent. Al. [1]

H. H. Abram, *Microstructure of Arc-Welded Steel* (Paper read before Institution of Welding Engineers: Electrical Review, Dec. 12, 1924, vol. 95, p. 890). An examination of specimens of butt- and lap-welded plates of medium carbon steel shows that the maximum depth to which the structure of the welded plate is affected does not exceed 0.1 inch. The first effect of heating up by the deposition of metal is to over-heat the material, thus causing the formation of a coarse structure. By the deposit of additional layers of new metal the grain becomes refined, but on the surface the coarse structure persists. Where practicable the whole welded article should be annealed.

C. R. Darling, *Some Scientific Aspects of Welding* (Engineer, Jan. 23, 1925, vol. 139, p. 113). A discussion of welding problems in connection with oxy-acetylene and arc welding.

J. J. Crowe and G. L. Walker, *Oxygen Purity and Cutting Efficiency* (Paper read before the American Welding Society: Iron Age, Mar. 19, 1925, vol. 115, pp. 824-827). Results are presented of tests carried out to determine the effect of small increases in purity of oxygen in oxy-acetylene cutting of steel. The results show that small increases in oxygen purity greatly increase the efficiency of cutting operations, both as measured by oxygen consumption and by cutting time. The effect is of considerable magnitude for the interval of 99 per cent. to 99.5 per cent. oxygen purity, showing a saving of approximately 12 per

cent. for oxygen consumption, and an equivalent saving in time. Any increase in purity beyond 99.5 per cent. has little effect.

A. S. Kinsey, *Steel under the Oxy-acetylene Flame* (Transactions of the American Society for Steel Treating, Oct. 1924, vol. 6, pp. 515-524). The application of the oxy-acetylene flame to the heating and melting of steel is briefly discussed. Its use in local hardening and carburising is noted.

R. Thomas, *Present Condition of the Autogenous Welding and Cutting of Metals* (Bulletin de la Société des Ingénieurs Civils, Jan.-Mar. 1924, pp. 182-203).

W. L. Warner, *Arc Welding with Metallic Electrodes* (Chemical and Metallurgical Engineering, Feb. 2, 1925, vol. 32, pp. 206-208). The fundamentals of the electric arc welding process are discussed.

M. Lebrun, *Electric Arc Welding with Metallic Electrodes* (Revue de Métallurgie, Aug. 1924, vol. 21, pp. 484-495). The characteristics of various types of electrodes are discussed and the factors which determine the correct size of electrode and the arc voltage have been investigated. The results are given in the form of tables and curves.

H. Nesse, *Electric Arc Welding* (Zeitschrift des Vereines Deutscher Ingenieure, Oct. 25, 1924, vol. 68, pp. 1125-1132). A general discussion of practice in electric arc welding. The strength of riveted and welded seams is compared. Direct current gives a better weld than alternating, but is more costly. The comparative costs of riveting as compared with welding are given.

Achenbach, *Arc Welding of Castings* (Giesserei Zeitung, Oct. 1, 1924, vol. 21, pp. 417-422). In arc welding castings the use of carbon electrodes has been largely superseded by that of iron rods, since these give better results. Cast-iron electrodes can be successfully used in the case of hot welding, but they must have high carbon and silicon, low manganese, and must be free from phosphorus and sulphur. For cold-welding, steel or iron electrodes of various compositions are used, and for selection of the most suitable it is advisable to make a test weld of the material in the first place.

E. J. B. Willey, *The Mode of Retention of Nitrogen in Electric Arc Weld Metal* (Journal of Society of Chemical Industry, Aug. 1, 8, 1924, vol. 43, pp. 263-266-T, 267-270-T.) The experiments conducted by the author show that upon burning an iron arc in nitrogen, appreciable quantities of iron nitride are formed. Such evidence as has been obtained appears to show, however, that exposure of heated iron to activated nitrogen does not result in any appreciable combination of the elements in question. The oxidation of the metal has no effect in this connection. Neither ferric oxide nor magnetic iron oxide absorbs nitrogen upon being heated in the gas, whether it be activated or not. Upon burning an iron arc in air the products appear to contain a second nitrogenous substance, distinct from a nitride, and owing its origin to the influence of the oxygen. It is suggested that this substance may be nitro-iron or some related compound formed by the action of the oxides

of nitrogen upon the iron vapours or upon the iron oxide present. The presence of 1 per cent. oxygen in the atmosphere in which the arc burns is sufficient to lead to the formation of the second and unidentified nitrogenous substance. Some interesting results might be obtained by allowing a stream of some easily oxidisable gas, such as hydrogen or acetylene, to impinge upon the weld. In this way an arc surrounded by an atmosphere nearly free from nitrogen or oxygen might be obtained with a correspondingly improved metal, due to the diminution or prevention of oxidation or nitrogenation.

C. H. S. Tupholme, *Welded Joints in Cast Iron Pipe* (Iron and Coal Trades Review, Apr. 17, 1925, vol. 110, p. 617). The application of bronze welded joints in cast iron pipe is dealt with. Particulars are included of the strength properties of joints made with tobin bronze.

Calorising, Coating, Tinning, Galvanising, Enamelling.—A. Fry, *Heat-Resisting Metal Objects* (Kruppsche Monatshefte, Feb. 1925, vol. 6, pp. 27–33). Certain metals, such as aluminium, can be applied to steel articles in a manner which causes them to penetrate the surface by diffusion. Steel parts so treated become highly resistant to heat and also to corrosion, and the process is being extensively developed in the manufacture of steel apparatus for chemical purposes.

A. W. Sinnamon, *Fireproofing of Structural Steel* (Address before the American Institute of Steel Construction: Iron Age, Mar. 5, 1925, vol. 115, pp. 694–696). The thermal expansion of steel in steel structures is briefly discussed, and the principles of fireproofing structural steel and various protective materials are dealt with.

R. Perrin, *The Penetration of Bronze into Steel at High Temperatures* (Revue de Métallurgie, Sept. 1924, vol. 21, pp. 531–538). An illustrated description of the method of obtaining an adherent lining, either internal or external, of bronze, in the case of steel articles in which special strength and toughness are required. The steel surface must be very smooth, and should be tinned before the hot bronze is poured thereon. The very perfect junction which results is of the nature of a cemented case, the bronze actually penetrating the steel. In the case of nickel steel the action is even more intimate, due, no doubt, to the fact that copper and nickel will readily alloy with each other in any proportion.

F. L. Estep, *The Manufacture of Tinplate in India* (Paper read before the American Iron and Steel Institute, Oct. 24, 1924). A detailed description is given of the tinplate plant erected at Jamshedpur, and operated by the Tata Iron and Steel Co. A special feature of the plant is the inclusion of air-cooling devices, hooded and water-cooled furnaces, and the extensive use of water-cooled floors, to relieve the effect of outside temperature or humidity, which is far more trying than at any tinplate plant in other countries. The hot mills consist of three units of two double mills each. The cold-roll department consists of four sets of rolls, three in tandem. The hot mills are equipped with six

"Steele" mechanical doublers. All these mills are electrically driven. The black pickling is done on a Grey machine, and six Thomas-Davies machines are in use for white pickling and tinning.

Tinplate Doubling Machine (Iron and Coal Trades Review, Mar. 6, 1925, vol. 110, p. 401). Particulars are given of the improvements in the design of the Thomas and Davies doubling machine in operation at the Melingriffith Works.

R. M. Crawford, *Recovering Pickling Acid Waste* (Iron Trade Review, Oct. 9, 1924, vol. 75, pp. 948-949). The customary methods of copperas recovery from waste sulphuric acid pickling solutions are unprofitable. Of other methods available, those making recovery in the form of iron oxide appear to be most attractive, since the iron oxide can be used in the blast-furnace. The calcining of copperas with the subsequent formation of iron oxide is a long-established industry. In the calcining operation the copperas decomposes into iron oxide, sulphur trioxide, sulphur dioxide, and water. Due to inefficient contact with the heating flame, the final oxide is contaminated with some undecomposed sulphate, which is removed by leaching the crude oxide with water. Attempts have been made to recover the sulphur trioxide vapours from the waste calciner gases in the form of sulphuric acid, but the results so far have not been encouraging, since any acid thus recovered must be very dilute (20 to 30 per cent.), due to the presence of large quantities of water vapour from the decomposition of copperas. Certain modifications of the above process for making iron oxide particularly adapted to processing waste iron sulphate solutions at their source, offer a simple and very practical method whereby the iron oxide is produced as before, but the sulphuric acid is recovered as concentrated acid (60 to 66 Bé).

C. A. Crawford, *Designing the Pickling Department for Economy in Manufacture* (Iron Trade Review, Apr. 2, 9, 16, 1925, vol. 76, pp. 875-877, 935-937, 1003-1006). A series of articles dealing with pickling practice and equipment.

J. L. Schueler, *A New Method for Zinc-Coating Wire* (Paper read before the American Electrochemical Society, Apr. 1925). The paper deals with "galvannealing," a new hot process for zinc-coating wire. A brief comparison is made between the ordinary hot process and galvannealing. The new process differs from the old process in that wiping of the coating is obviated and a new step introduced—heat treatment of the zinc coating—which smooths the coating, distributes it uniformly over the surface of the wire, and makes the heavy coating malleable and flexible. Methods for analyses of coatings are briefly discussed, including the Preece or copper sulphate test. The galvannealed coating is shown to be composed of an outside layer of zinc, an intermediate layer of FeZn_{10} , inside layers of FeZn_{10} and FeZn_7 , and finally a layer of FeZn_3 next to the surface of the wire.

J. L. Schueler, *Improved Process for Galvanising Wire* (Mining and Metallurgy, Dec. 1924, vol. 5, pp. 580-581).

S. Cowper-Coles, *Methods of Testing Galvanised Iron* (Engineering, Dec. 19, 1924, vol. 118, p. 825). The copper sulphate test is still used, but is unsuitable for zinc coatings applied by the electro or Sherardising processes. For everyday works practice the sulphuric acid test is probably the best, as giving both the thickness of the zinc and the evenness of distribution. Other methods of testing are briefly described.

S. Cowper-Coles, *Apparatus for Electro-Zincing Small Articles* (Metal Industry, Oct. 10, 1924, vol. 25, pp. 345-348). The author describes various classes of apparatus for plating small articles such as rivets, washers, nails, and similar articles. The most practical machines are those which have only a small cathode contact exposed. Some of the machines described have quite as much metal deposited on the contact surfaces as on the articles themselves. Low voltage is also a considerable factor, ensuring every article getting an equal coating.

S. Cowper-Coles, *Electro-Galvanising of Sheets* (Metal Industry, Oct. 24, 1924, vol. 25, pp. 393-394). A short account is given of certain types of electro-galvanising plant for sheets.

S. Cowper-Coles, *The Electro-Galvanising Industry* (Electrician, Nov. 28, 1924, vol. 93, pp. 611-613, 619). The author discusses the developments in the electro-deposition of zinc and gives some details of various processes.

H. Bablik, *The Composition of Zinc Coatings* (Metal Industry, May 15, 1925, vol. 26, pp. 481-482). A brief description is given of tests showing the composition of zinc coatings obtained by the various processes of hot-galvanising, electro-plating, sherardising, and spraying.

A. Malinovszky, *Enamelling Defects due to Cast Iron* (Journal of American Ceramic Society, Jan. 1925, vol. 8, pp. 72-78). In cast iron parts intended for enamelling a low combined carbon and an evenly distributed graphitic carbon in a very minute state will ensure no signs of blistering. If the combined carbon is high, and if temper carbon is present, blistering of the enamel is certain. The changes in the combined carbon during the enamelling process produce a radical difference in the structural composition of the castings which is not without effect on the enamel. All finished castings should have a uniform thickness, otherwise chipping, lifting, or pinholes are certain to occur.

H. Allen, *Electric Japanning* (Paper read before the American Electrochemical Society, Oct. 1924). A brief review of the development of electrically heated enamelling ovens, and the progress made in the art of enamelling automobile parts at the Dodge motor-car plant.

Detinning of Scrap.—J. Jackson, *Development of Methods for the Collection and Disposal of House (Domestic) Refuse* (Transactions of the Society of Engineers, 1924, pp. 21-46). In this paper brief particulars are given of the plant in operation at Birmingham for the detinning of cans by electro-chemical methods. The cans are first passed through a toothed crushing machine which serves the dual purpose of reducing their bulk and perforating them, so that at a later stage the electrolyte

easily percolates. The cans are conveyed from the crushing room to the vat room in cages. There are two vats, each capable of holding five cages. Each cage holds about 150 lbs. of cans, and the time taken for detinning is approximately twenty minutes. Copper plates form the cathodes. The electrolyte consists of a solution of caustic soda and stannous chloride. The working temperature is 80°C ., 500 amperes at 5 or 6 volts is used, and the treatment costs about 25 kilowatt-hours per ton of cans. The tin is recovered and sold in the form of a grey powder containing 77 per cent. pure tin.

PHYSICAL AND CHEMICAL PROPERTIES.

Properties and Tests of Cast Iron.—P. Goerens, *Methods for the Improvement of Cast Iron* (Stahl und Eisen, Jan. 29, 1925, vol. 45, pp. 137–140). The author discusses the structure of white cast iron and grey cast iron, showing the dependence of the strength properties and toughness upon the structure of the material, and indicating how to produce the structural constituents which are necessary to ensure castings of good quality.

E. Piwowsky, *The Improvement of Cast Iron by the Addition of Alloy Metals* (Stahl und Eisen, Feb. 26, 1925, vol. 45, pp. 289–297). Experiments were made to determine the influence of various alloy metals on the properties of cast iron. For the cast-iron samples a Swedish pig iron was taken containing total carbon 4·01, silicon 0·04 to 0·06, manganese 0·13 to 0·14, phosphorus 0·018 to 0·02, and sulphur 0·011 to 0·02 per cent., and three series of alloys were prepared containing silicon 1, 1·75, and 2·75 per cent. The series of alloy metals added were aluminium up to 0·1 per cent., titanium up to about 1 per cent., nickel up to 2 per cent., chromium up to 0·5 per cent., nickel + chromium in the proportion of 2 and 0·5 per cent., vanadium up to about 1 per cent., tungsten up to about 0·5 per cent., molybdenum up to about 1 per cent., tungsten + vanadium up to 0·5 and 0·25 per cent. each, molybdenum + vanadium up to 1 and 0·25 per cent. each. The test-bars were used as cast, without machining, being 2 centimetres diameter, resting on supports 40 centimetres apart. The results of the bending, compression, hardness, and impact tests are given in tables in great detail. Tensile tests were also made on a number of tensile test-bars 10 millimetres diameter and 80 millimetres long. In general, aluminium strongly promotes the formation of graphite, and raises the transverse strength of cast iron by about 25 per cent., with little or no effect on the deflection; the specific work of rupture by impact is increased 25 to 50 per cent.; and the hardness and resistance to compression diminish by 20 to 30 per cent. Titanium has much the same effect as aluminium on the bars containing low and medium silicon, but in the high-silicon series ($\text{Si} = 2\cdot66$) the mechanical properties, including transverse strength, hardness, and resistance to compression, were improved by titanium. Nickel improves all the mechanical properties by 20 to 30 per cent.; while chromium by itself has little influence except on the hardness, which rises by 20 to 25 per cent. with 0·5 per cent. chromium. Nickel and chromium together improve all the properties, and the presence of chromium acts very much as a check to the tendency of nickel to promote formation of graphite. Vanadium in the low and medium silicon

series ($Si = 1$ and 1.75 per cent.) very greatly increases the transverse strength, resistance to compression, and hardness; in the high silicon series the effect of vanadium is not nearly so marked. Tungsten also improves all the mechanical properties in the medium silicon series, but care is necessary in adding tungsten, since it does not readily dissolve in cast iron on account of its high melting point. Molybdenum has much the same effect as tungsten, and in fact these two elements appear to influence the cast iron more favourably than any of the other metals, on account of the tendency of both to form mixed crystals with the iron.

E. Piwowarsky, *The Improvement of Cast Iron by Alloy Additions* (Foundry Trade Journal, Apr. 16, Apr. 23, 1925, vol. 31, pp. 331-334, 345-346). An English translation of the foregoing paper which appeared in *Stahl und Eisen*.

C. H. Desch, *Presidential Address to the Institute of British Foundrymen* (Foundry Trade Journal, Jan. 8, 1925, vol. 31, pp. 23-24). Recent developments in the improvement of the quality of cast iron and the characteristics of pearlitic cast iron are reviewed.

J. E. Hurst, *Notes on Pearlitic Cast Iron* (Paper read before the Institute of British Foundrymen; Foundry Trade Journal, Oct. 16, 1924, vol. 30, pp. 327-332). A discussion of the merits of pearlitic cast iron produced by the Lanz process of Diefenthaler. Pearlitic cast iron is defined as a cast iron having essentially a low silicon and a low carbon content. This cast iron, when cast normally, would have a white fracture, but when cast in warm moulds or cooled slowly in the mould under special conditions has a structure consisting solely of pearlite and graphite. The composition and rate of cooling are varied to comply with these conditions for any particular thickness. The properties claimed for pearlitic cast iron produced according to the Lanz process are summarised as follows: (1) High tensile, transverse strength and toughness; (2) high resistance to impact stresses; (3) moderate hardness when properly treated; (4) only a slight tendency to the formation of pipe; (5) great resistance to abrasion; (6) fine dense structure, the structure being unaffected by temperature changes, and (7) a certain amount of ductility. Some of the principles underlying the production and properties of pearlitic cast iron are discussed, and the author concludes that the influence of pearlitic structure in itself is considerably overstressed, and it is undoubtedly to the size, arrangement, and distribution of the graphite and the crystals that the strength properties are due. The pearlitic structure in itself is a distinct advantage from the point of view of resistance to wear and to certain distortion under influence of heat.

Pearlitic and Lanz Iron (Foundry Trade Journal, Feb. 5, 1925, vol. 31, pp. 117-119). A discussion from a practical standpoint of the characteristics of pearlitic cast iron.

C. Irresberger, *Pearlitic Cast Iron* (Foundry, Dec. 1, 1924, vol. 52, pp. 941-943). The production and properties of pearlitic cast iron are briefly discussed.

A. Logan, *The Structural Composition of Cast Iron* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, Feb. 19, 1925, vol. 31, pp. 155-160). The constitution of cast iron is dealt with, and the influence of the elements on the structure and properties is discussed.

J. Ward, *Carbon Control Gauges Strength* (Foundry, Apr. 1, 1925, vol. 53, pp. 281-282). The structure and properties of pearlitic cast iron are briefly discussed.

A. Marks, *High Tensile Cast Iron* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, Dec. 25, 1924, vol. 30, pp. 545-547). The factors involved in the production of high tensile cast iron are discussed. The increase of tensile strength by the addition of steel to the mixture and the production of pearlitic cast iron are considered.

E. Schüz, *The Graphite Eutectic in Cast Iron* (Stahl und Eisen, Jan. 29, vol. 45, pp. 144-147). A method is described by which grey iron castings of high quality with over 3 per cent. silicon can be regularly produced at will, in which the greater part of the free carbon is contained as eutectic graphite. The characteristic structure of this cast iron is shown by means of micrographs.

J. E. Hurst, *The Graphite Eutectic in Cast Iron* (Foundry Trade Journal, Apr. 23, 1925, vol. 31, pp. 353-354). A review of the work of Schüz (Stahl und Eisen, Jan. 29, 1925).

J. E. Hurst, *The Formation of Graphite in Cast Iron* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal Apr. 16, 1925, vol. 31, pp. 326-330). The author reviews the mechanism of the formation of graphite in cast iron. The subject is discussed under the following headings : Formation of graphite ; condition of carbon in solution in the liquid alloys ; temperature at which graphite commences to form ; the formation of graphite from the primarily formed carbide.

M. Hamasumi, *The Distribution of Graphite in Cast Iron and the Influence of Other Elements on its Strength* (Science Reports of the Tôhoku Imperial University, Nov. 1924, vol. 13, pp. 133-178). The effect of cooling velocity on the strength of cast iron has been studied. The strength increases considerably with the cooling velocity, the cause of which is principally attributed to the uniformly distributed graphites-in-whirl. The mechanism of the growth of graphite, especially whirling graphite, is discussed, and the cause of black fracture and the formation of the network structure in cast iron are explained. The influence of carbon, silicon, phosphorus, sulphur, manganese, copper, chromium, and tin has also been studied.

E. Piwowsky, *Some Remarkable Phenomena concerning Graphite Formation in Solidified Grey Pig Iron* (Stahl und Eisen, Mar. 26, 1925, vol. 45, pp. 457-458). After casting some round bars of 20 millimetres diameter, the fracture showed curious white and grey concentric rings with a white core. Microscopic examination showed that the only structural constituents throughout were graphite and ferrite, and the

difference in colour of the rings can only be ascribed to the type of graphite formation, as influenced by the cooling conditions.

J. E. Hurst, *The Influence of Manganese on Cast Iron* (Foundry Trade Journal, Nov. 13, 1924, vol. 30, pp. 417-419). The influence of manganese on cast iron is shown by a summary of the results obtained by various investigators.

J. E. Hurst, *The Influence of Phosphorus on Cast Iron* (Foundry Trade Journal, Nov. 20, 1924, vol. 30, pp. 433-436). The influence and mode of occurrence of phosphorus in cast iron is summarised from the work of Stead, Wüst, and others.

J. E. Hurst, *The Influence of Sulphur in Cast Iron* (Foundry Trade Journal, Oct. 30, 1924, vol. 30, pp. 377-380). During the last few years the importance attached to the presence of sulphur as a source of certain troubles appertaining to grey iron castings has considerably declined. The work of previous investigators on the condition and influence of sulphur in cast iron is summarised. Sulphur in the presence of sufficient manganese exists almost wholly as the sulphide of manganese— MnS . In this form it is practically without influence on the structure and properties of cast iron. In the absence of sufficient manganese the sulphur exists as the iron sulphide, which is soluble in the liquid iron and has the tendency to prevent the formation of graphite. The actual mechanism of its influence in this respect is still obscure, but it is obviously connected with its solubility in the iron. Additional confirmatory evidence of the insolubility of the manganese-sulphur content, its lower specific gravity, and its lack of influence on the condition of the carbon in cast iron is also given.

R. H. Palmer, *Sulphur as a Hardening Agent* (Foundry, Nov. 15, 1924, vol. 52, pp. 894-896). The author describes a series of experiments carried out to determine the relative hardening value of varying amounts of sulphur added to iron which later was poured in chill moulds.

P. D. Merica, *Nickeliferous Cast Iron* (The Canadian Foundryman, Aug. 1924; Iron and Steel of Canada, Apr. 1925, vol. 8, pp. 86-87). The presence of nickel in cast iron causes increased graphitic carbon formation; that is, nickel tends to make the iron grey, 1 per cent. being equal, perhaps roughly, to $\frac{1}{4}$ to 1 per cent. of silicon in this respect. The nickel does not form carbides, but dissolves in the ferrite of the iron. If the composition is such that combined carbon is present in castings containing 1 to 5 per cent. nickel, the structure will be fine, resembling sorbite rather than pearlite. The use of nickel appears to be justified when maximum hardness and fine grain are required for readily machinable grey iron. Nickel chromium cast iron, on the other hand, is chiefly of use where maximum hardness is required and the casting does not need to be machined.

F. C. Edwards, *Testing Castings* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Jan. 1, 1925, vol. 31, pp. 10-14). The testing of castings with a view to improvement in design is discussed.

H. C. Dews, *The Transverse Test of Cast Iron* (Foundry Trade Journal, Apr. 23, 1925, vol. 31, pp. 350-352). Developments in the transverse testing of cast iron are reviewed.

A. Campion, *Some of the Factors which Influence the Strength of Cast Iron* (Paper read before the Association Technique de Fonderie: Foundry Trade Journal, Jan. 22, 1925, vol. 31, pp. 67-70).

C. Cury, *Testing Cast Iron for "Life"* (Paper read before the Association Technique de Fonderie, Nov. 6, 1924: Foundry Trade Journal, Jan. 15, 1925, vol. 31, pp. 52-55). The term "coulabilité," or "life," originated by Portevin is defined as the property which a metal possesses of filling a mould more or less completely. The term "fluidity," which was long used to designate this property, is inappropriate, since fluidity is a physical property affecting only the metal itself, whereas "life" has to do with both the metal and the mould. In the investigations described by the author the Remy test-bar and a modification of this were used. The experiments were carried out to ascertain the effect of certain factors in the pouring of castings. The Remy test-bar is a helically wound cylindrical 6-millimetre rod, on which gauge marks are fixed at intervals of 50 millimetres. It is provided with a gate placed at the side of the mould and a reservoir placed below the feed and beneath the plane of the spiral. The principle consists in letting the metal flow into the test-bar through a strickled aperture obtained by means of a sand core and at a level which is practically constant, the latter condition being secured by means of a very wide lost head, so that the surface of the liquid metal undergoes but little fluctuation due to irregularities in pouring. The purpose of the reservoir placed at the drag is to prevent the metal penetrating into the spiral before the feed box is completely filled, so as always to maintain the same rate of flow.

D. H. Ingall and H. Field, *"Peeling" in White-Heart Malleable* (Paper read before the Iron and Steel Institute, May 1925: this Journal, p. 265).

Properties and Tests of Wrought Iron and Steel.—K. Honda, *Definitions of Steel and Cast Iron* (Science Reports of the Tôhoku Imperial University, Nov. 1924, vol. 13, pp. 187-191). A definition of steel based on the method of production is not appropriate: for when a new method has been discovered the definition will have to be altered; and a material having the same constituents and properties as a steel cannot be called a steel so long as its method of production is not known. Again, the definition based on the properties of steel is also inadequate: for the words "hard," "tough," and "elastic" are all relative, and therefore the intensity of these properties cannot be determined above or below which a material can be called a steel. According to the author, steel may be defined as an iron-carbon alloy with a content of carbon lying between 0.035 and 1.7 per cent. On this definition wrought iron may be a steel lowest in carbon content. Cast iron is defined as an iron-carbon alloy with a content of carbon between 1.7 and 6.7 per cent.

F. T. Sisco, *The Chemistry of Iron and Steel* (Transactions of the American Society for Steel Treating, Feb. 1925, vol. 7, pp. 197-216). The first of a series of articles dealing with the chemistry of iron and steel. It includes introductory remarks and a discussion of the occurrence, importance, and relationship of the common elements found in iron and steel, as well as the occurrence and relationship of alloying elements in these materials.

Effect of Sulphur on Structural Steel (Fifth Preliminary Report of the Joint Committee of the U.S. Bureau of Standards, the U.S. War Department, and the U.S. Navy Department, appointed for the Investigation of Phosphorus and Sulphur in Steel: Proceedings of the American Society for Testing Materials, 1924, vol. 24, Part I., pp. 185-205. Note: The Third and Fourth Preliminary Reports of the Committee are printed with discussion, in the same volume, pp. 96-184). The structural steel which forms the subject of the fifth preliminary report had an approximate carbon range of 0.16 to 0.22 per cent. Six heats of basic open-hearth steel with sulphur varying from approximately 0.03 to 0.08 per cent. were made under the direction of the Committee. The sulphur was residual—that is, it was present in the steel through its presence in the materials charged into the furnace, and not through additions made in the ladle or mould. Tensile, impact, hardness, bend, and shear tests were made upon specimens with axes respectively parallel and perpendicular to the long dimension of the plate. The material in general rolled satisfactorily, but, in rolling ingots from three heats of higher sulphur, some trouble was experienced from cracked edges and breaking up. The heat treatment and the method of performing the various tests on the treated material are described, the results of the tests being presented in the form of graphs and in tables. An extended discussion of the results and the publishing of any conclusions drawn therefrom has been deferred and will form the subject of a future report.

C. Canaris, *Use of Basic Bessemer Steel for Rails of High Tensile Strength* (Stahl und Eisen, Jan. 8, 1925, vol. 45, pp. 33-38). Observations on the wear of rails in service extending over periods up to seventeen years show that per million tons of traffic dead weight the average rate of wear of a basic Bessemer rail is rather less than that of open-hearth and acid Bessemer rails with about the same Brinell hardness. It is still usual to denounce the use of basic Bessemer rails on the ground of high phosphorus content, but it is shown that with good modern practice it is an easy matter to produce basic steel in the converter with phosphorus between 0.02 and 0.03 per cent. before recarburising, and the final product has not more than 0.045 to 0.05 per cent. phosphorus. By careful selection of raw materials, scrap, and additions, the author has been able to produce regularly basic steel of a tensile strength of 74 to 78 kilogrammes per square millimetre, with an elastic limit of 62 to 65 per cent. of the tensile strength. The rails rolled from this steel contained carbon 0.5, phosphorus 0.05 to 0.07, sulphur 0.04 per cent. The surface hardness was 15 to 40 Brinell units higher than the internal

hardness. Wear tests on an Amsler machine show that these basic Bessemer steel rails compare very favourably with open-hearth steel rails. It was also found that phosphorus up to 0.08 per cent. improved the resistance to wear, which confirms the observations of other investigators that phosphorus up to about the amount stated increases the hardness much more than the brittleness.

A. Wimmer, *Influence of Oxygen on the Physical and Technical Properties of Mild Steel* (Stahl und Eisen, Jan. 15, 1925, vol. 45, pp. 73-78). Samples of steel containing different amounts of oxygen were prepared by adding iron oxide to molten steel containing carbon 0.05, manganese 0.38, phosphorus 0.045, and sulphur 0.035 per cent. Nine samples altogether were obtained, containing 0.1, 0.15, and 0.20 per cent. of oxygen. All the mechanical properties, including notch toughness and Brinell hardness, were adversely affected by the addition of oxygen. Plasticity, both in the hot and in the cold state, greatly deteriorated, and micrographs of etched sections show that grain-size increases with increasing oxygen content.

J. K. Smith, *Nitrogen in Steel—Prevention or Cure?* (Iron Age, Nov. 6, 1924, vol. 114, pp. 1209-1210). The author discusses the presence of nitrogen in iron and steel and its elimination. The low-temperature reduction of iron in the blast-furnace is advocated as a preventive.

C. McKnight, jun., *Making Steel Castings Stronger* (Iron Age, Feb. 12, 19, 1925, vol. 115, pp. 469-472, 555-557). The influence of nickel, chromium, and other elements on the properties of steel castings is dealt with. The production, heat treatment, properties, and uses of alloy steel castings are also discussed.

R. H. Greaves and J. A. Jones, *Temper-Brittleness of Steel: Susceptibility to Temper-Brittleness in Relation to Chemical Composition* (Paper read before the Iron and Steel Institute, May 1925: this Journal, p. 231).

W. T. Griffiths, *Note on Nitrogen as a Possible Factor in Temper-Brittleness* (Paper read before the Iron and Steel Institute, May 1925: this Journal, p. 257).

J. R. Cain, *Influence of Sulphur, Oxygen, Copper, and Manganese on the Red-Shortness of Iron* (United States Bureau of Standards, 1924, Technologic Paper No. 261; see also this Journal, 1924, No. II. p. 427).

H. Sutton, *The Brittleness of Zinc-Plated Steel* (Paper read before the Faraday Society: Metal Industry, May 15, 1925, vol. 26, pp. 483-484). The author describes experiments which tend to confirm previous assumptions that the embrittling effect is due to hydrogen. It was found that neutral sulphate baths gave the best results with only a very small embrittling effect. In any case, however, with a thin coating and suitable surface conditions, the steel tends to recover from the embrittling effect.

H. J. French and W. A. Tucker, *Available Data on the Properties of Irons and Steels at Various Temperatures* (Proceedings of American Society for Testing Materials, 1924, vol. 24, Part II., pp. 56-87). The

authors discuss the effect of high temperatures on the physical and mechanical properties of steel. Conclusions from a large number of tests show that the effect of temperature rise to about 600°C . is to reduce tensile strength, proportional limit, and the elastic modulus, and greatly to increase ductility and the tendency to creep. From the standpoint of high strength and limit of proportionality of steels at high temperatures, the temperature scale may be divided roughly into three parts: (1) the range 20° to 450°C .; (2) the range 450° to 600°C .; (3) above 600°C . In the lowest range high strength and proportional limits are functions of composition and heat treatment. Combinations giving highest strength at ordinary temperatures show similar superiority throughout the entire range. In the second range, the benefits to be derived from heat treatment are limited (except in the lower portion of the range), and high strength and limit of proportionality are more largely functions of composition. On this basis it appears possible to improve the properties of steel by adding such elements as chromium, cobalt, uranium, molybdenum, and vanadium. The drop in strength and proportional limit of steels at temperatures around 550°C . is permanent for most practical purposes, and it is improbable that commercial steels can be produced to withstand continuously fairly large loads at temperatures above 650°C . except when one or more alloy elements are added in such large proportion as to reduce the iron content to so low a value that the resulting product can hardly be called steel. An extensive review of other investigators' work is given.

V. T. Malcolm, *Methods of Testing at Various Temperatures and their Limitations* (Proceedings of American Society for Testing Materials, 1924, vol. 25, Part II., pp. 15-55). The author presents a comprehensive review of the most recent methods of testing metals at various temperatures. He notes that furnaces and other apparatus and the procedure used by the various investigators differ and are by no means standardised, and there is little definite information on the rational mechanical testing of metals at high temperatures. The effect upon the physical properties of metals of raising the temperature cannot yet be stated in terms of a definite law. Generally, however, the tensile strength and elastic limit of steel decrease, and the elongation and reduction of area increase, as the temperature rises, except that the tensile strength is found to rise up to a certain temperature variously recorded as between 260° and 425°C . The elastic limit, however, declines steadily from the beginning of the rise in temperature. Therefore to use the tensile strength as a basis of design of structures or apparatus exposed to considerable variations of temperature would be dangerous. The whole subject of the behaviour of metals at high temperatures requires further study.

The two foregoing papers form the chief contributions to a symposium on effect of temperature upon the properties of metals. To the papers is appended an extensive bibliography of the principal literature on the effect of high temperature on the properties of metals (pp. 128-140).

Higher Steam Pressures and Temperatures (Engineer, Nov. 28, 1924, vol. 138, pp. 606-607). Steam pressures of 350 to 400 lbs. have now become standard, according to the reports of the Prime Movers Committee of the National Electric Light Association, and designs of boilers for higher pressures are contemplated. The chief difficulty in adopting such high pressures is the high temperature which the material is called upon to withstand. At 400 lbs. steam has a temperature of about 725° F. (385° C.), and this is about the limit at which a boiler of any known alloy steel can be safely worked at present. For steam valves nickel copper alloys have been found suitable for resisting the high temperatures of the steam, in particular an alloy known as Davis metal has been developed with an elastic limit of 35,400 lbs. at 1000° F. (537° C.).

F. Körber, *Influence of Temperature on Strength Properties of Cast Steel* (Stahl und Eisen, Dec. 25, 1924, vol. 44, pp. 1765-1770). Three kinds of cast steel were examined as to their tensile properties at 400° to 500° C. One was an ordinary Bessemer steel made in a small converter; No. 2 was a basic open-hearth steel made in a 23-ton furnace, and the third was an electric steel, containing 0.24 per cent. nickel, made in a 5½-ton Heroult furnace. Two specimens of each steel were taken, one of which was retained for testing in the condition as cast, the other being annealed and cooled in air. The yield point showed a tendency to decrease as the temperature rose, but the ultimate strength showed for the open-hearth steel a maximum of 56 kilogrammes per mm.² at about 300°. Impact tests were carried out on the three steels up to 500° C., the notch toughness rising to a maximum of 16 metre-kilogrammes per cm.² in the open-hearth steel at 100°, the fracture changing progressively from granular to fibrous. The elongation and contraction reached minimum values between 100° and 300°, which was not due to brittleness at blue heat, as the notch-toughness was good.

F. Körber and A. Pomp, *Tensile Properties of Steel Castings at High Temperatures* (Mitteilungen a. d. Kaiser-Wilhelm Institut für Eisenforschung, 1925, vol. 6, No. 4, pp. 21-31).

E. Siebel, *Behaviour of High Quality Steels under Forging and Rolling Conditions* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1675-1678). An investigation of the strength of steels at high temperature and of the influence of the speed of displacement on the hot tensile strength. Under a dynamic hot tensile test the strength after speeds of displacement of 6.4 to 6.6 cubic millimetres per second at 900° C. was increased by 200 to 300 per cent. above that obtained under a static tensile test.

F. C. Lea, *The Effect of Low and High Temperatures on Materials* (Paper read before the Institution of Mechanical Engineers, Dec. 5, 1924: Engineering, Dec. 12, 19, 1924, vol. 118, pp. 816-817, 843-845). Describes tests made for the purpose of studying the influence of temperatures from 0° to 500° C. on the tensile properties of carbon steels

and alloy steels. Comparative impact tests and hardness tests were also made.

P. Eyermann, *Steels at Highest Working Temperatures* (Iron Age, Nov. 13, 1924, vol. 114, pp. 1270-1273). The author has studied the strength and other properties of carbon and alloy steels at 500° to 1200° C. The steels tested were three carbon steels with 0·05, 0·70, and 1·40 per cent. carbon respectively, a 2 per cent. silicon steel, a 2 per cent. chromium steel, a 3 per cent. tungsten steel, a low-carbon steel with 3 per cent. nickel and 1 per cent. chromium, and a commercial high-speed steel. With increase in temperature the tensile strength and ultimate stress decrease, but only disappear at the melting point. The proportional elastic limit likewise decreases, and there is a marked increase in the tendency to flow under slowly applied loads. Similarly the elongation increases with temperature in all the steels tested except the 2 per cent. silicon steel and the nickel-chromium steel. In these two cases minimum or low elongation values are shown in the neighbourhood of 1000° C. In commercial carbon steels the reduction of area increases generally with temperature, but the changes are very small above 950° C. In the alloy steels tested the changes encountered with temperature vary widely with the composition of the steel. However, a marked increase in reduction of area up to 700° or 800° C. is observed in all five alloy steels; at higher temperatures only a small increase, similar to that in carbon steels, is shown in the 2 per cent. chromium steel and the 3 per cent. tungsten steel, while a sharp decrease and minimum values are found in the neighbourhood of 1000° C. for the nickel-chromium steel and the 2 per cent. silicon steel. This range of "reduced malleability," which is to be avoided in hot working these steels, is followed by a rapid increase and high values of reduction of area at 1200° C.

D. H. Ingall, *The Mechanical Properties of Metals at Elevated Temperatures* (Journal of the Birmingham Metallurgical Society, vol. 8, pp. 515-524). A review of the work of previous investigators.

V. A. Davidenkoff, *Researches on the Variations in the Mechanical Properties of Steel in Terms of the Temperature, as regards Tensile Tests* (Annales du Bureau de Mécanique Agricole, Pétrograd, 1917, vol. 41, Special number; Revue de Métallurgie, Aug. 1924, vol. 21, pp. 365-370). A lengthy abstract accompanied by descriptions and illustrations of the apparatus used and diagrams and photomicrographs of the results. A bibliography is appended. Amongst the conclusions arrived at, it is stated that both the mechanical results and the photomicrographs are, so far as a 0·10 per cent. carbon steel is concerned, in agreement with the theory of the existence of an amorphous cement.

E. Maurer and R. Mailänder, *Blue-Brittleness* (Stahl und Eisen, Mar. 19, 1925, vol. 45, pp. 409-423). The characteristics of blue-brittleness as revealed by the notch-bend test are of two kinds: those associated with cold brittleness, and those associated with hot brittleness. Cold brittleness occurs at low temperatures and is characterised

by crystalline fracture, without appreciable deformation, and a small expenditure of work. The influence of shape of test-piece, speed of blow, and previous treatment is discussed and defined. Hot brittleness occurs at higher temperatures, and is due to a diminution of the capacity to undergo deformation. The theory of the blocking of the slip planes should be further studied and tested.

J. R. Freeman and A. T. Derry, *Effect of Hot-Rolling Conditions on the Physical Properties of a Carbon Steel* (United States Bureau of Standards, 1924, Technologic Paper No. 267). A study has been made of the following five factors of rolling conditions, namely, initial temperature of rolling, finishing temperature, total reduction, pass reduction, and roll speed on the following physical properties of a medium carbon steel: Tensile properties (ultimate strength, yield point, proportional limit, elongation, reduction of area), resistance to impact, hardness, microstructure, and density. The steel was rolled in one direction only, in order to study the effect of unidirectional rolling on the properties of the steel in the direction longitudinal and transverse to that of rolling. The results obtained indicate that the total reduction and finishing temperature are the most important factors in rolling. A change in these conditions has a greater influence on the mechanical properties of the steel than either of the other three factors studied, which were found to have very little influence. An increase in total reduction decreases the ultimate strength and increases the yield point, ductility, and impact resistance. A slightly lower ultimate strength, but greater yield point, ductility, and impact resistance were obtained with a finishing temperature of 700° C. as compared with a finishing temperature of 1000° C. Unidirectional rolling causes a slight difference in the mechanical properties of the steel between the longitudinal and transverse directions; the properties in the transverse direction are, in general, inferior. Normalising the rolled plate tends to eliminate all differences produced by the different rolling conditions. The density of the steel is the same in the cast and rolled conditions and is not affected by rolling conditions.

W. J. Crook, *Rolling Refines Grain Structure* (Iron Trade Review, Nov. 20, 1924, vol. 75, pp. 1365-1369). The author has studied the physical properties and metallographic characteristics of hot rolled steel. Experiments show that the grain-size produced by hot-rolling may be further refined by subsequent annealing. With steel of low carbon and high manganese content, about 0.74 per cent., a great increase in hardness may be produced by quenching. Contrary to the usual accepted theory that no change in grain-size occurs below the transformation point, it is found that the grain-size is increased in measurable amount by heating to temperatures even 100° F. below the transformation point.

F. Pacher and F. Schmitz, *Comparative Investigations on the Behaviour of High Quality Steel when Forged under the Hammer and under the Press* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1668-1674). Steels containing different percentages of chromium and tungsten and a nickel steel were subjected to forging tests and also to impact and tensile tests.

The values obtained from impact and tensile tests on hot specimens showed remarkable agreement with the results of forging tests, both under the hammer and under the press.

O. Emicke and M. Rodenbach, *Reduction of Section in the Rolling of Round Steel Bars with Varying Carbon Content* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1679-1681). A discussion of the influence of carbon content, speed of rolling, and temperature on the reduction of section of bars to be finished round.

R. H. Greaves, *Gun Wire: The Effect of Low Temperature Heat Treatment on the Properties of Cold-Strained Steel and its Behaviour under Stress at Raised Temperatures* (Research Department, Woolwich, Report No. 60, 31 pp.). The investigation was undertaken with the object of providing a material which would maintain a condition of constant stress with constant strain at a given temperature whatever the variation, within certain limits, of strain and temperature to which it was subjected in use. It is concluded that if it is required to ensure a constant tension in the wire at atmospheric temperature, in spite of considerable variation in the temperatures to which it may be subjected in use, the wire must be heat-treated at a temperature not below 200° C. The lower limit of the temperature of preliminary treatment (in excess of 200° C.) is fixed by the fact that it must be above any temperature to which the wire is likely to be subjected in use. On the other hand, the upper limit of temperature of treatment is governed by the tension which is to be maintained. The higher the tension the less must the temperature of treatment exceed 200° C.

Data are provided from which the relation between stress, temperature, and preliminary treatment of the wire can be determined.

Sometimes the conditions of stress and maximum temperature attained are such that a slight fall in tension cannot be avoided. In such circumstances reheating of the wire (now under reduced tension) to any temperature below the previous maximum causes no further reduction in the tension.

R. H. Smith, *Some Physical Properties of Low-Carbon Steel* (Transactions of the American Society for Steel Treating, May 1925, vol. 7, pp. 569-580). The object of the paper is to tabulate and describe the practical results obtained by the heat treatment of low-carbon steels with an accurate control of heating temperature and media of quenching. The results show that the tensile strength per square inch and other physical properties, such as elongation, reduction of area, and hardness, may be accurately controlled in their relationships to each other, and may be varied over a wide range by suitable quenching. Practically any physical properties which have heretofore been demonstrated as possible to secure by heat-treating and subsequent tempering at a proper temperature may likewise be obtained in a single quench by accurately controlling the cooling medium, its velocity and temperature, and the correct temperature of the steel from which the quench is made.

L. Guillet and A. Portevin, *The Influence of Tempering on the*

Mechanical Properties of Steel after Reheating (Comptes Rendus, Feb. 2, 1925).

J. V. Howard and S. L. Smith, *Recent Developments in Tensile Testing* (Proceedings of the Royal Society, Jan. 1925, vol. 107, A, pp. 113-125). When material has passed into the condition of non-proportional elasticity, the removal and reapplication of the load causes a loop to be traced in the recorded load-extension diagram. Looping is a general property of metals, and the loops obtained from different metals have distinguishing characteristics. The researches described were made with a view to investigating the factors influencing the formation of the loops and to studying the effect of variation in composition on the looping properties, with special reference to tests on steel.

J. M. Lessells, *The Elastic Limit in Tension and its Influence on the Breakdown by Fatigue* (Paper read before the Institution of Mechanical Engineers, Dec. 5, 1924 : Engineering, Dec. 12, 1924, vol. 118, pp. 813-814). Tensile and fatigue tests were made to determine the degree of influence which the elastic properties of materials exert on the actual breakdown by fatigue of those materials. An attempt is made to show that the endurance limit or true elastic limit is related to the ultimate stress in tension alone. The endurance limit value, while being related to the ultimate stress in tension, is largely influenced by two factors : internal stress as measured by the relative position of yield stress and elastic limit, and microstructure. The importance of the elastic limit is such that all fatigue tests should be analysed with the tensile test results as a background.

R. W. Chapman, *A New Form of Extensometer* (Quarterly Bulletin of the Institution of Engineers, Australia, Jan. 1925, vol. 2, pp. 23-26).

Physical Properties of Materials : I. Strengths and Related Properties of Metals and Wood (United States Bureau of Standards, 1924, Circular No. 101). The present edition of this report, which has been enlarged to about four times the size of the first edition, includes additional material which has appeared in the technical literature during the past few years. It contains the values for tensile, compressive, and shearing strengths, ductility, modulus of elasticity, and other related properties of pure metals and their alloys and of wood. In addition to these, the properties of metals at elevated temperatures, their fatigue and impact properties, and the effect of heat treatment and cold-working are given. Other properties and uses of the less commonly used metals are described briefly. Graphical representation is used in many cases to show the change of the properties of a material with changing conditions.

H. Thyssen, *The Determination of the Mechanical Properties of Cast Parts* (Revue Universelle des Mines, Feb. 15, 1925, vol. 5, pp. 186-198). Specifications usually stipulate that castings should be tested, the tests imposed being shock and slow bending tests, and tensile tests on comparatively large test-pieces from the same metal and cast at the same time as the castings themselves. There are many objections to such methods, which, while at times applicable to steel castings, may be

unsuited to iron castings. The low elongation values of cast iron necessitate very exact centring of the test-piece in the machine, and in any case a tensile testing machine almost invariably gives a breaking strain far lower than the true breaking strain of the material. The principles involved and the methods employed in testing cast iron on Frémont bend test and shearing test machines are described and illustrated.

P. Heymans, G. R. Brophy, and A. L. Kimball, jun., *The Photoelastic Method for the Determination of Causes of Failure of Metal Structures* (Transactions of the American Society for Steel Treating, Oct. 1924, vol. 6, pp. 505-514). This paper embodies the results obtained through the study of the stresses set up in pinion gears, resulting from design and methods of assembly. A brief description and discussion of the photoelastic method of stress analysis is incorporated in the paper.

H. Wright, *Bearing of Elastic-Limit Tests on Steel* (Paper read before the Cleveland Institution of Engineers: Iron and Coal Trades Review, Apr. 10, 1925, vol. 110, p. 586).

F. Sommer and F. Rapatz, *The Scientific Testing and Investigation of High Quality Steels* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1739-1743).

P. Ludwik and E. Schen, *Comparative Tensile, Compression, Torsion, and Rolling Tests* (Stahl und Eisen, Mar. 12, 1925, vol. 45, pp. 373-381).

R. W. Chapman, *A New Machine for Experiments in Torsion* (Quarterly Bulletin of the Institution of Engineers, Australia, Jan. 1925, vol. 2, pp. 21-23). Most of the ordinary torsion machines measure the twisting force on the specimen by means of a system of levers. These usually have the disadvantage that they allow of twisting only in one direction, and the accuracy of the balancing depends upon the skill of the operator. In the machine described, which has been constructed in the testing laboratory of the Adelaide University, the balancing is automatic, and the bar may be twisted in either direction, so that complete hysteresis diagrams of the behaviour of the material may be obtained.

J. Seigle, *The Question of Torsion in the Manufacture of Metallic Cables: The Principles of Cabling Machines* (Revue de l'Industrie Minérale, Mémoires, Oct. 15, Nov. 1, 1924, pp. 485-501, 514-522). A detailed and mathematical investigation of the various problems which arise in the manufacture of metallic cables and of the principles underlying such manufacture, and the chief types of machines employed for coiling and stranding.

J. Seigle, *Certain Effects Due to Permanent Torsion in Steel Bars of Circular Section* (Revue de l'Industrie Minérale, Mémoires, Dec. 15, 1924, pp. 568-574). An article similar to the above, but dealing with steel rounds of larger section. The factors of elongation and deformational viscosity of the steel are discussed.

H. Herbst, *The Bend Test for Wire Rope Strands, by Alternate Bending of the Wires* (Glückauf, Nov. 29, 1924, vol. 60, pp. 1111-1120). The method of testing wires for wire ropes by bending them alternately

to left and right through an angle of 90° is described, and an apparatus for the performance of such tests is illustrated. The results of bending tests on wires, plain and galvanised, are tabulated. Over 18,700 wires of diameters ranging from 1.5 to 2.9 millimetres, and with tensile strength from 160 to over 180 kilogrammes per square millimetre, were tested, the mean number of bends for each group of wires being taken as the bending number for that size. Comparative results of tests on wire in single strands, and after spinning into a rope, are also tabulated.

W. A. Scoble, *Wire Ropes Research* (Report presented to the Institution of Mechanical Engineers, Dec. 19, 1924 : Engineering, Dec. 26, 1924, vol. 118, pp. 856-860). The present report is the second one of the Wire Ropes Research Committee. The results of bending tests over pulleys of different diameters are described.

G. Klein and A. Aichholzer, *The Hardness Bending Test as a Means of Controlling the Charge in the Manufacture of High-Quality Steel, particularly Plain Carbon Steel* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1734-1739). It is suggested that by means of hardness bending tests on sample bars of standard size, subjected to an exact specified heat treatment, the condition of the melt in a steel furnace, working on high-carbon steel, may be sufficiently well judged, and the composition estimated within narrow limits.

P. Oberhoffer and M. Toussaint, *A Process for the Development of the Hartmann Lines* (Stahl und Eisen, Oct. 23, 1924, vol. 44, pp. 1330-1332). Various methods have been prescribed, notably one by Fry (Stahl und Eisen, 1921, vol. 41, p. 1093) for showing up the Hartmann or Lüders' lines on the bright surface of a steel specimen subjected to deformation. The authors have now devised an electrolytic method, using as electrolyte a solution of hydrochloric acid with an admixture of iron chloride. An illustration is given of a piece of boiler plate after electrolytically etching for half an hour in a solution of 300 grammes of FeCl_3 , 10 cubic centimetres of hydrochloric acid, and 3000 cubic centimetres of water. An auxiliary current of 0.8 ampere was supplied to the bath by a battery. The method is much more rapid and cheaper than Fry's method.

J. D. Jevons, *Strain Detection in Mild Steel by Special Etching* (Paper read before the Iron and Steel Institute, May 1925 : this Journal, p. 191).

T. H. Turner and J. D. Jevons, *The Detection of Strain in Mild Steels* (Paper read before the Iron and Steel Institute, May 1925 : this Journal p. 169).

G. Wazau, *Annealing Brittleness in Steel* (Zeitschrift des Vereines Deutscher Ingenieure, Nov. 15, 1924, vol. 68, pp. 1185-1190). Three typical fractures of steel parts are illustrated and described, and the cause of fracture is explained as due to the superimposition of cold-working (in its widest sense). Annealing brittleness is revealed by etching with Fry's etching medium, which brings out the lines observed by Fry on the surface of a piece of steel that has been strained. These lines do not disappear on heating the article to the temperature which

will restore toughness, and the existence of these sheaves of lines cannot therefore be taken as a sure sign of brittleness.

L. B. Tuckerman and C. S. Aitchison, *Design of Specimens for Short-Time "Fatigue" Tests* (U.S. Bureau of Standards, 1924, Technologic Paper, No. 275). This paper discusses the controlling factors in the design of short-time fatigue test specimens, which differ from those of the endurance-run type of fatigue test. In endurance runs it is necessary to secure failure at a place where the stresses are determinate and calculable. In short-time fatigue tests failure is not desired. It is possible to design the short-time fatigue specimen with maximum stresses uniform over a large portion of the material, thus securing greater sensibility. This should be the controlling factor in the design of these specimens. Specimen shapes are shown suitable for different types of test. The Sondericker type of rotating beam fatigue machine, with a plain cylindrical specimen or a specimen with a slightly reduced cylindrical section between load bearings, seems best suited for these tests, combining high sensibility with a simple specimen shape.

L. Jannin, *Some Results of Vibration Tests on Metals* (Revue de Métallurgie, Dec. 1924, vol. 21, pp. 742-749). A machine is described for testing the resistance of steel rods to repeated continuous or alternating shocks, a property intimately connected with the elastic limit of the material. An unevenly balanced fly-wheel is made to rotate rapidly between two steel arms, pierced near one end with holes to receive the axis of the wheel, and hinged at the far end to a lug on the bedplate of the machine, so that the two arms can move freely up and down. The extreme ends of the arms, beyond the axis of the fly-wheel, are bored with two further holes, through which the ends of the test-piece are passed. The middle of the test-piece rests on a slab of metal projecting upwards from the machine bed. The contrivance thus resembles a compound lever, hinged at one end. The fly-wheel is rendered unbalanced by a portion of the metal being removed on one side. Its rapid revolution is thus attended by the transmission of continuous shocks to the test-piece. The degree of shock can be increased by allowing a certain amount of play between the ends of the test-piece and the holes in the arms through which they pass. Some results of vibration tests are described.

A. Ono, *Experiments on the Fatigue of Steel* (Memoirs of College of Engineering, Kyushu University, 1924, vol. 3, pp. 51-85). The effect of heat treatment was studied on a 0.25 per cent. carbon steel, and on two nickel-chrome steels containing nickel 2.75, chromium 0.88, and nickel 4.24, chromium 1.14 per cent. respectively, and the results are stated and explained. The rate of cooling from the temperature of reheating affects the resistance to fatigue, rapid cooling giving a higher resistance than slow cooling.

H. J. Gough, *Fatigue in Metals* (Paper read before the British Acetylene and Welding Association: Foundry Trade Journal, Dec. 18, 1924, vol. 30, pp. 527-528). Fatigue is defined as the process by which

metals could be fractured by repeated cycles of stress insufficient to cause failure at a first application. It is shown that there is no relation determinable between fatigue range and the tensile limit of proportionality, yield stresses, and impact value. Ultimate tensile strength is the only mechanical property permitting correlation with the reversed bending stress range. As the Brinell number was directly related to the ultimate tensile strength, a very accurate estimate of the fatigue range might be obtained by carrying out a ball indentation test. The effect of speed and surface scratches on the fatigue range are briefly discussed.

D. J. McAdam, jun., *The Endurance Range of Steel* (Proceedings of American Society for Testing Materials, 1924, vol. 24, Part II., pp. 574-600). The results of the investigation show the superiority of steel of high elastic ratio as well as high tensile strength for fatigue-resistant machinery parts. Increase in the elastic ratio increases the ratio of endurance limit to tensile and torsional strength. With a steel of high elastic ratio, therefore, the endurance range is greater in proportion to tensile and torsional strength than with steel of low elastic ratio. With high elastic ratio it is possible to utilise the full endurance range with wide variation in the ratio of minimum to maximum stress. With low elastic ratio the full endurance range can be utilised only when the range is between nearly equal and opposite stresses. The results have practical application in the design of machinery parts that are subject to torsion fatigue, and are of special value in the design of heat-treated alloy steel shafting.

L. Aitchison and L. W. Johnson, *The Effect of Grain upon the Fatigue Strength of Steels* (Paper read before the Iron and Steel Institute, May 1925 : this Journal, p. 351).

New Fatigue-Testing Machine (Iron Age, Dec. 4, 1924, vol. 114, p. 1482). A brief description is given of the new Amsler fatigue-testing machine.

L. Aitchison, *Notched-Bar Impact Tests at Low Temperatures* (Aeronautical Research Committee, Oct. 1924, Reports and Memoranda, No. 922). The report gives the results of an investigation of the notched-bar values of steels at temperatures below the normal. Six series of tests were carried out at air temperature and also at 0°C ., -40°C ., and -80°C . A constant temperature of 0°C . was obtained by using an ice bath, and for temperatures of -40°C . and -80°C . frozen mercury and solid carbon dioxide were employed respectively. The results indicate that the toughness of nickel-chromium steels, as indicated by the notched-bar test, is not seriously affected by low temperatures. Some of these steels, however, show a slight fall in the notched-bar value. The majority of the plain carbon steels tested give a marked drop in the notched-bar value at low temperatures below that obtained at air temperature. With the greater number of steels tested, the maximum drop on the notched-bar values occurs between air temperature and -40°C . Between -40°C . and -80°C . the drop, if any, is small, and in some cases there is an apparent rise in the value. Cold-worked materials

depreciate very seriously in notched-bar value with the fall in temperature. The effects are due to the presence of the notch, and are obtained whether the test-piece is 5×5 mm. or 10×10 mm. There would appear, therefore, to be good reasons for the use of hardened and tempered nickel-chromium steels for any important parts which may be reduced in temperature, such as the exposed parts of aircraft flying at considerable altitudes.

F. Körber, *Influence of Previous Treatment on the Notch Toughness of Mild Steel in the Cold and in the Hot State* (Mitteilungen a.d. Kaiser-Wilhelm Institut für Eisenforschung, 1925, vol. 6, Part 5, pp. 33-43). The work of previous investigators is critically reviewed, showing that they differ considerably in their conclusions concerning the dependence of the notch toughness on the temperature. The conflicting views are undoubtedly due to differences in the structure, due to different heat treatments. Determinations of notch toughness have been made on mild steel specimens at temperatures ranging from -70° to 500° C., and in various conditions produced by rolling, tempering, overheating, critically deforming, annealing, and rolling at blue heat. Tough mild steel gives a maximum value for notch toughness at temperatures round about room temperatures, but brittle steel gives its maximum value at about 200° . Some conclusions of practical value are drawn from these results.

M. Moser, *A New Method of Interpreting Notched-Bar Impact Test Results* (Transactions of the American Society for Steel Treating, Mar. 1925, vol. 7, pp. 297-320). The author describes methods of interpreting notched-bar impact test results. Not only is the area of the cross-section at the notch used in computing the results of the impact of the pendulum, but also a considerable volume of metal surrounding the notch. This affected volume absorbs a certain portion of the impact energy. Illustrations showing the effect of the impact on the area surrounding the notch are presented, and tables and curves dealing with this problem are included.

O. H. Basquin, *Tangent Modulus and the Strength of Steel Columns in Tests* (United States Bureau of Standards, 1924, Technologic Paper, No. 263). The tangent modulus describes the semi-elastic action of a material when subjected to excessive stress, being defined as the ratio of the rates of increase of stress and of strain at that stress. In 1889 Engesser suggested that if this modulus is used in Euler's formula in place of Young's modulus, the resulting formula should be appropriate for estimating the strength of columns of ordinary proportions. To test the accuracy of this proposition, the author has made a study of more than 200 column tests.

L. B. Tuckerman and C. S. Aitchison, *An Analysis of the Deformation of the Mooring Spindle of the "Shenandoah"* (United States Bureau of Standards, 1925, Technologic Paper No. 270). This report presents the results of the examination and tests on the mooring spindle of the U.S. Navy airship *Shenandoah*, which was bent when the airship broke

from her mooring mast during a storm on Jan. 16, 1924. The mooring spindle was wrenched free from the ship and remained attached to the mast. The object of the examination and tests was to determine as closely as possible the actual wind forces which acted upon the ship at the time she broke away. Although the forces which produced permanent deformation in the structure cannot, in general, be determined with accuracy, an approximate method of analysis and examination was developed applicable to any axially symmetrical deformed structure. Among the conclusions reached by this analysis are that the material evidently met specifications for yield point, and also that the load producing deformation was certainly greater than 13,400 lbs. and probably greater than 27,000 lbs.

W. R. D. Jones, *D-Links for Colliery Tram Shackles* (Proceedings of the South Wales Institute of Engineers, 1925, vol. 41, No. 1, pp. 75-115). The author presents the results of an examination of the properties and strength of a number of wrought iron and steel D-links used for colliery tram-shackles.

A. L. Badochine, *Methods of Testing and the Technical Conditions in Inspecting Metals and Metal Parts* (Société Russe de Métallurgie, Nos. 9-12, Part 1, 1923, pp. 101-103). An account of Russian views and requirements in relation to testing and inspection, emphasising the need for standardising the methods now in vogue.

G. A. Hankins, *Report on Effects of Adhesion between the Indenting Tool and the Material in Ball and Cone Indentation Hardness Tests* (Engineering, May 1, 1925, vol. 119, pp. 556-557).

G. A. Shires, *Some Practical Aspects of the Scratch Test for Hardness* (Ibid., p. 557). These reports form a contribution to the hardness tests research carried out under the auspices of the Institution of Mechanical Engineers. The first contains the results of experiments with the object of supplementing the knowledge of results of ball or cone indentation tests when adhesion between the indenting tool and material is considered.

The second paper describes the construction of a sclerometer specially designed for scratch tests, and comparative measurements were made of the widths of scratches on materials from Brinell hardness 203 up to 653. A table is given which shows the limitations of the scratch-test, illustrating the small differences noticeable in the scratch widths for a comparatively great difference in hardness, the whole range of 450 Brinell numbers only corresponding to a scratch width variation of one hundredth of a millimetre; moreover, above about 300, ranges of considerably more than ten Brinell numbers are embraced by 0.5μ , the limit of sensibility of measurement available. In addition to instances in which the Brinell test is impossible owing to mechanical circumstances peculiar to the work in question, there are at the same time cases where the scratch test is superior to the ball or other tests by virtue of its physically distinct nature. The fact that the scratch test sometimes enables the detection of hardness differences not apparent by the

indentation method, as with sprayed coatings, and with "superhard" materials, suggests that a slightly different property or combination of properties is being measured. The division of hardness into types from the standpoint of definition and method of measurement as by indentation, scratching, or abrasion, indicates the diversity of the property, and it is probable that the scratch test does actually give values for scratch hardness as a distinct property of matter. At the same time the scratch test is somewhat in the nature of an indentation test, so that comparison between the Brinell and scratch tests would appear justifiable.

M. Moser, *Observations on the Brinell Ball Test* (Stahl und Eisen, Mar. 5, 1925, vol. 45, pp. 343-344). The resistance of crystallites to the entry of the ball varies according to the direction of the crystal axis. In certain positions of the axis the impression becomes four-cornered instead of circular. The hardness measurements, depending on the regular form of the impression, can therefore be taken as accurate only if the crystallites of a material are of so small size as to form practically an amorphous conglomerate into which the ball is pressed.

R. Mailänder, *Duration of Loading and Ball Hardness* (Kruppsche Monatshefte, Oct. 1924, vol. 5, pp. 209-213). It has been observed that in carrying out the Brinell hardness test the hardness readings apparently depend upon the time during which the full load on the ball is maintained, and many tests have been made to determine the influence of the duration of loading. The usual method of making such tests has been to make a number of impressions under variable duration of loading, but as there is no certainty that the material is uniformly regular, an exact determination of the influence of the duration of loading can only be obtained by taking average values. Another method has been tried by making a test of short duration, and, after measuring the impression, the ball is placed again on the impression and the same pressure is applied for a given time, after which the impression is again measured. This method has also proved to have several disadvantages, and a different process has been evolved at Krupp's laboratories. In this the variation of the depth of impression as a function of the duration of loading is measured at given intervals of time, within a single test, and without removing the pressure. For this purpose the Martens mirror is employed, and the method of testing and results obtained are described. In the case of a soft iron having a Brinell hardness of about 80, curves show that even after a steady application of the load for five minutes equilibrium is not reached. For hard steel equilibrium was established after one minute, but with very soft steel, as for iron, equilibrium was not attained after five minutes. In general, for both hard and soft steel the variation due to increased duration of loading does not exceed 3 per cent., so that a testing time of, say, ten seconds will give results within 3 per cent. of those obtained after a period of five minutes. For iron the same results are found after a loading period of twenty seconds, but for softer metals a period of at least two to three minutes should be allowed.

S. C. Spalding, *Comparison of Brinell and Rockwell Hardness of Hardened High-Speed Steel* (Transactions of the American Society for Steel Treating, Oct. 1924, vol. 6, pp. 499-504). The author compares the hardness of high-speed steels as measured by the Brinell and Rockwell testers. The steels were tested at varying temperatures, and the hardness numbers obtained are tabulated and shown by means of curves.

I. H. Cowdrey, *Relation between Rockwell and Brinell Hardness Scales* (Transactions of the American Society for Steel Treating, Feb. 1925, vol. 7, pp. 244-260). The author has investigated the relation between the hardness values for various materials as determined by the Rockwell and Brinell testing machines.

H. P. Hollnagel, *Hardness Numbers and their Relation* (Iron Age, Nov. 27, 1924, vol. 114, pp. 1404-1406, Mar. 12, 1925, vol. 115, pp. 770-773). The ideal physical state in metals is reviewed. The true hardness of the most perfect type of crystalline material would be considered to be the pressure necessary to displace an atom from its position in the lattice (at a particular temperature). Since the force with which an atom is repelled by its neighbours is the true force of restitution and resistance, there exists a certain depth beyond which deformation will cease to occur because of the difficulty of penetration of one atom into another. Beyond this point rupture takes place by atoms shearing past each other, under which condition true hardness has no significance. If the definition "Hardness is the cohesive resistance to deformation" is to be accepted, only an average value of hardness, atomically speaking, can be referred to, for a true hardness as defined in terms of the atom can have but little significance in metals as they are used in practice. The stress strain curve is discussed in detail, and the author concludes that to ascertain satisfactory relations between hardness numbers from a physical standpoint, they must be reduced to a common language, *i.e.* work per unit volume per unit strain.

Brinell Hardness Numbers (U.S. Bureau of Standards, 1924, Miscellaneous Publication No. 62). A table for converting the diameter of Brinell impressions to Brinell hardness numbers. The table gives the values of both the 3000 and 500 kilogramme Brinell hardness numbers with the standard 10-millimetre ball for diameters of impression varying from 2.00 to 6.99 millimetres by steps of 0.01 millimetre.

R. L. Smith and G. E. Sandland, *Some Notes on the Use of a Diamond Pyramid for Hardness Testing* (Paper read before the Iron and Steel Institute, May 1925 : this Journal, p. 285).

P. Dufour, *Method of, and Apparatus for, Determining the Hardness of Metal Objects* (Chimie et Industrie, May 1924, pp. 317-318). The apparatus consists essentially of two jaws, each carrying a ball for making simultaneous hardness tests on both sides of an object, equal pressures being applied to both balls. The balls are then replaced by plates made of plastic material such as lead, to take an impression of the indentations made by the balls. It is claimed that this test gives an indication of the homogeneity of the metal.

P. Dufour, *Processes and Methods for Verifying the Hardness of Metal Parts* (Revue de Métallurgie, Mémoires, June 1924, vol. 21, p. 340).

H. C. Dews, *Talks on Testing* (Machinery, Jan. 8, Mar. 26, 1925, vol. 25, pp. 459, 839; Apr. 23, May 14, 1925, vol. 26, pp. 102-103, 211-212). The author outlines some of the outstanding features in the mechanical testing of materials, Brinell hardness, and machinability; the scleroscope, shape and size of tensile bars are discussed, and the technical terms used in testing are defined.

P. Nicolau, *Investigation of the Jannin Method of Testing the Wear of Metals, and its Application to Anti-Friction Metals* (Revue de Métallurgie, June 1924, vol. 21, pp. 347-355). The Jannin method consists in measuring the depth of an imprint produced, not by pressure, but by friction under constant load, and approximates therefore to the Brinell method. The conditions under which it can be applied are analytically discussed, with formulæ and equations showing the relation it bears to ordinary hardness tests. True wear tests depend on the amount of metal actually removed, and this too can be ascertained by means of the Jannin tests. Its results are not perfectly accurate when applied to viscous metals, such as those used for anti-friction purposes.

L. Jannin contests the conclusion arrived at by P. Nicolau as to the test not being applicable for ascertaining the amount of wear in soft metals, and points out that in certain circumstances, which he describes, accurate indications can be obtained.

K. Honda and R. Yamada, *Some Experiments on the Abrasion of Metals* (Paper read before the Institute of Metals, Mar. 1925). The authors have carried out experiments with an apparatus similar to that used by Robin to investigate the abrasion, in the first place, of soft metals, such as copper, cadmium, lead, magnesium, tin, antimony, zinc, and bismuth by cast-iron plates, and, in the second place, of carbon steels by emery discs. In the experiments on carbon steels samples of Swedish steel were used. These steels were tested in different conditions—i.e. the normalised martensitic, troostitic, and sorbitic structures. In the first place, the steel was tested, in both the normal and martensitic conditions, to see whether the proportionality between the amount of wear and the frictional horse-power held good, as in the case of former metals, the coefficient of friction being kept constant. It was found in this case also that the amount of wear was proportional to the frictional horse-power—that is, the relative coefficient of abrasion was constant, provided that the coefficient of friction remained constant. Next the change in the amount of wear due to varying coefficient of friction was investigated by using emery-wheels varying in roughness. As in the case of former metals, the frictional horse-power was reduced to 15×10^{-4} .

Next, the relation between the coefficient of abrasion and the carbon content under a constant coefficient of friction, say, 0.32, was given. In the normalised condition, the amount of wear decreased steadily from 0.1 to 1.1 per cent. of carbon; in the sorbitic structure it decreased gradually up to 0.7 per cent. of carbon content, and then increased again

in the case of a higher percentage of carbon. In the troostitic structure, the amount of wear was least in a 0.9 per cent. carbon steel, but in the case of the martensitic structure it decreased from 0.1 to 0.3 per cent. of carbon and then increased gradually up to 1.1 per cent. of carbon content. Comparing the amounts of wear in each case, the wear of steels was greatest under the normalised condition, and became less in the sorbitic, troostitic, and martensitic structure; but in high-carbon steels the wear of martensite increased beyond that of troostite and sorbite.

R. M. Brown, *Effect of Cold-Drawing on some Properties of Steel and Iron* (Paper read before the Institution of Engineers and Shipbuilders in Scotland, Feb. 10, 1925: *Iron and Coal Trades Review*, Feb. 20, 1925, vol. 110, pp. 302-303). The author has investigated certain effects of cold-drawing. A series of experiments was carried out to investigate the effects and limitations of a single pass. Bars of the same material but of different diameters were cold-drawn to a final diameter of 0.45 inch. The speed of drawing was kept as nearly constant as possible. Steel was used of the following composition: Carbon 0.115, silicon 0.048, phosphorus 0.051, sulphur 0.037, and manganese 0.530 per cent. The steel was heated to 750° C., and was allowed to cool slowly.

Tests were carried out immediately after drawing, and at various intervals of time ranging from one day's rest to six months' rest or longer.

In summarising his conclusions, the author remarks that cold-work is directly proportional to percentage reduction of area when the reduction has been carried out in a single pass and the final diameter after drawing is the same in each case.

The modulus of elasticity is practically unaffected by cold-drawing. Immediately after drawing the modulus is slightly below its normal value. Heat treatment may produce vast changes in the properties and structure of the metal; cold-drawing elongates the crystals, practically destroys the general elongation, and may almost double the tensile strength, and yet the modulus will be relatively unaffected. It appears to be practically independent of the nature of the structure. For cold-drawn mild steel the variation in the properties of the aged material, expressed as percentage of the corresponding property of the annealed material, are: Modulus, 3.5 per cent.; ultimate strength, 62.3 per cent.; elongation, 30.6 per cent.; reduction of area, 30.1 per cent.

For mild steel the limit of proportionality is increased by cold-drawing, but it is not greatly affected by the severity of the pass. A slight tendency to increase with increased percentage reduction of area in a single pass was shown. The limit proportionality is greatly affected by ageing.

The Izod value for mild steel is greatly reduced even by slight reductions of area in drawing. The minimum value recorded was in the neighbourhood of 30 per cent. reduction of area.

H. Eicken and W. Heidenhain, *Influence of Speed of Drawing, Reduction of Cross-Section and Carbon Content on the Mechanical Properties of*

Drawn Steel Wires (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1687-1694). The influence of speed of drawing on steel wires containing 0.26 per cent. and 0.83 per cent. of carbon is investigated and the results are shown in tabular form and in diagrams. One set of tests was made in which the reduction was 15 per cent. per draught, a 5-millimetre wire being drawn down to 2.7 millimetres in eight drawings. A second set was made with a reduction of 25 per cent. per draught, and a third set with a reduction of 35 per cent. per draught. In the first tests the lower carbon wire increased in tensile strength from 85 to 110 kg./mm.² and the high carbon wire from 146 to 180 kg./mm.² With the greater reductions per draught and the same speed of drawing (1.40 metre per second) the tensile strength increased to 136 and 215 kg./mm.² respectively.

A. Pomp, *The Cold-Rolling of High-Quality Steel* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1694-1696). The changes in the tensile properties of steel strip and steel sheets due to cold-rolling are discussed, and the influence of cold-rolling on the properties is shown by the aid of diagrams. The effect of spheroidal cementite on the hardening capacity of cold-rolled steel is referred to.

R. Gross, *Cold-Working and Recrystallisation* (Zeitschrift für Metallkunde, Sept. 1924, vol. 16, pp. 344-352). Experiments were performed on rods of rock-salt and gypsum to demonstrate the dependence of the bending strength on the inner constitution of the crystal and not on the crystal surface. Crystal substances distorted by cold-bending recrystallised on being suitably heat-treated.

F. Körber, *Deformation and Recrystallisation* (Stahl und Eisen, Feb. 12, 19, 1925, vol. 45, pp. 217-223, 261-265). Theoretical considerations of the changes in the properties of metals brought about by cold-working and annealing, and discussion of the accompanying phenomena.

W. Schneider and E. Houdremont, *Recrystallisation of Carbon Steels and Alloy Steels* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1681-1687). An attempt to study the recrystallisation phenomena by means of hot tensile tests and the observation of the cold-working effect occurring above the point of maximum load stress led to no exact results. Better success was obtained by an examination of the tensile properties of material deformed by cold-drawing and subsequently annealed at various temperatures. A manganese steel, a nickel-chromium steel, and two steels with low chromium and tungsten and high chromium and tungsten respectively were studied and the results are shown graphically.

M. Polanyi, *Crystal Deformation and Hardening by Cold-Work* (Zeitschrift für Metallkunde, Mar. 1925, vol. 17, pp. 94-95). When a fine-grained metal is subjected to cold-working, the crystallites along the boundaries of the slip planes break up into masses or heaps of very fine crystals, while the remaining grains become distorted, but are not broken up into smaller particles. This theory accounts for the fact that while X-ray analysis shows an increase in the number of lattice planes,

no corresponding increase in the number of grains can be detected metallographically.

G. Sachs, *The Hardening of Metals* (Zeitschrift für Metallkunde, Mar. 1925, vol. 17, pp. 85–93). The phenomenon of the hardening of metals by cold-work has been studied. The application of cold-work produces undulated bending of the slip planes, which causes distortion of the space lattice and the setting up of internal stress, which varies in different directions throughout the metal mass. The actual increase in the hardening of the metal depends upon the magnitude of the stress and the amount by which it varies. Annealing at relatively low temperatures causes recrystallisation and the internal stress then becomes equalised and the slip planes straighten out, the orientation of the crystals remaining practically unchanged. The structure of the recrystallised metal therefore becomes oriented similarly to the structure after deformation. The hardening of metals by the addition of another element forming a solid solution is due to the bulging of the slip planes caused by the entrance of new atoms into the lattice, and the degree of hardening which occurs depends on the relative sizes of the atoms of the solute and the solvent. Hardening by heat treatment may be brought about by one of three causes—the transformation of one solid solution into another, the precipitation of a new phase from an unstable solid solution, or the eutectoidal decomposition of a solid solution. In all cases the same laws apply as in hardening by cold-work, the internal stress being produced by changes of volume due to new atoms forming on the decomposition of the solid solution. The effect of decreasing grain size on the increase in the hardness of a metal may be explained by the greater irregularity in the distribution of the internal stress. No satisfactory explanation has been found for the changes in the resistance to separation of the crystals.

F. S. Dodd, *Grain Growth in Mild Steel* (Paper read before the Staffordshire Iron and Steel Institute, Nov. 21, 1924). The author points out that normal grain growth occurs in any metal, except cast metals, which is heated for a sufficient time at a sufficiently high temperature. When a metal is plastically deformed in the cold and then annealed under suitable conditions, very large grains result. Any excess of strain beyond a certain point causes the metal totally to recrystallise if annealed at the proper temperature. This is followed by grain growth if sufficient time is allowed. The author describes experiments carried out to ascertain (1) the limiting amounts of carbon which would give abnormal grain growth in steel; (2) the relation between the amounts of strain and the temperature of annealing below 700° C., and (3) the effects of varying carbon content on (2). The materials used in the investigation were Armeo iron and mild steels. The results of the experiments show that abnormal growth does not occur in Armeo iron whatever the degree or kind of deformation when annealed at 650° C., but all mild steels containing up to 0.25 per cent. carbon will, if sufficiently plastically deformed, grow large grains upon annealing between

600° C. and 700° C. If the temperature of annealing is too low no exaggerated grain growth will take place, however great the deformation. The grains in a strain-hardened steel which has been annealed at too low a temperature to produce growth would, upon annealing at the proper temperature, grow as if it had received no previous annealing.

E. Schiebold, *Cold-Working Phenomena in the Light of X-ray Research* (Zeitschrift für Metallkunde, Nov. 1924, vol. 16, pp. 417-425). The author discusses the work of previous investigators on the changes in the structure of metals caused by cold-working and subsequent heat treatment as revealed by X-ray examination, and the various theories of plastic deformation in the hot and cold state, as put forward by Tammann, Heyn, Koerber, and others, are critically discussed. The Laue spectrograms show that on subjecting the metal to slight deformation under tensile stress the elliptical interference points become elongated into short dark radial streaks. As deformation proceeds the streaks are distorted, and become more elongated across the direction of rolling, assuming a star-like appearance. Spectrograms of metals deformed by cold-rolling also show interference spots symmetrically arranged in relation to the direction of rolling, the symmetry of the figures being greater, the greater the degree of cold-rolling. By X-ray examination the nature of the deformation which a metal has undergone can be judged qualitatively, as well as the direction of the distortion and approximately the amount of distortion which has taken place, but whether individual crystal grains are split up cannot be accurately determined by this method. But it is clear that plastic deformation produces crystallographic displacement of the grains along a slip plane accompanied by rotation or slip along a plane of separation.

M. F. Fogler and E. J. Quinn, *Scratch and Brinell Hardness of Severely Cold-Rolled Metals* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). In the experiments carried out by Rawdon and Mutchler (Transactions of the American Institute of Mining and Metallurgical Engineers, 1924, vol. 70, p. 342) it was found that on continued cold-rolling the metal hardened up to a particular point and then reversed and became softer; this was true for both Brinell and scratch hardness values. The results of experiments carried out by the authors indicate that a reversal of hardness does not occur under all conditions of commercial rolling practice, but depends, probably, on local conditions of rolling.

W. Rosenhain and A. C. Sturney, *Cutting Tools Research* (Engineering, Jan. 30, Feb. 6, 1925, vol. 119, pp. 151-152, 178-179). The authors present a report of the Cutting Tools Research Committee of the Institution of Mechanical Engineers upon the results of an investigation, the object of which was to study the deformation and flow of metal under the action of a simple cutting tool, and more particularly to observe the manner of separation by which a chip is formed. The materials used for the cutting experiments were normalised mild steel with carbon 0.142 and manganese 0.650 per cent., and cast brass of the 60 to 40 type.

The depth of cut and top-rake angle and front clearance angle of the tool were varied in the case of each material. Three general types of chip have been observed, which are termed, (a) tear type, (b) shear type, and (c) flow type. Their general shape and characteristics are discussed and photomicrographs and drawings of typical sections are shown.

H. Pommerenke and R. Dewert, *Influence of Heat Treatment on the Cutting Capacity of High-Speed Steels* (Revue de Métallurgie, Mémoires, July 1924, vol. 21, pp. 371-395). Generally speaking, a carbon percentage of less than 0.55 renders a tool steel incapable of giving good efficiency. For steels with sufficient carbon the best behaviour is obtained in service by heat-treating them and quenching from about 1350° C. and subsequently annealing at 600° C. Tool steels are improved by having their "secondary" hardness—after heat treatment—raised to above their normal "hardness on quenching". The microscope gives most valuable information relative to cutting efficiency and heat treatment, the maximum service being obtained from tools the structure of which is a martensite matrix which contains the undissolved constituents such as vanadium carbide and iron tungstide. An austenitic structure indicates a steel with a poor cutting efficiency.

F. Rapatz and H. Pollack, *The Hardening of Steel* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1698-1703). General notes on hardening, the measurement of hardness, and the theory of hardness. In alloy steels manganese, nickel, and silicon tend to increase the brittleness of a cutting tool, while tungsten and chromium confer toughness.

E. Maurer and W. Haufe, *Influence of the Constituents generally regarded as Injurious to the Hardening of Tool-Steel* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1720-1726). In a hypereutectoid tool-steel the influence of additions of arsenic, copper, sulphur, and tin was studied, together with the effect of lowering the carbon, silicon, and manganese content, with a view to ascertaining the increase, if any, in the tendency to formation of hardening cracks and the change of volume on quenching. The lowering of the carbon had a bad effect in these directions, but the lowering of the silicon, and especially of the manganese, had a contrary effect, reducing the tendency to hardness cracking and increasing the hardening interval. Arsenic produced no effect on the hardening properties, but phosphorus and tin are both injurious. The only effect of sulphur was to increase the sulphide inclusions. The view that copper affects the hardening properties injuriously cannot be maintained.

W. Oertel and F. Pölguter, *Mechanical Properties of some High-Speed Steels in Comparison with their Cutting Efficiency* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1708-1712). The hardness of carbon steel, high-speed steels of different composition, and stellite was measured at temperatures ranging from room temperature to 1000° and 1100° C. The measurements of chromium-tungsten high-speed steels and of molybdenum and molybdenum-cobalt steels showed no great difference in hardness. In all these steels up to a temperature of 550° the Brinell number ranged from 670 to about 580; beyond that temperature a

sudden drop takes place which continues until at 1100° the hardness ranges from 104 to 75. Stellite shows no sudden drop in hardness, but it falls gradually from 630 to 370 Brinell as the temperature rises from 0° to 1050° , the curve following a straight line. As regards tensile strength the differences are small, and it is concluded that neither hardness nor tensile tests are a means of judging the cutting efficiency. The heat-conductivity might give some indication thereof, but experiments in this direction have not yet been made. Hot wear tests might also enable cutting efficiency to be determined.

O. Böhler, *The Technical and Economic Importance of High-Quality Steel* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1660-1664). The development of the production and use of special steels is described, and the benefit to the engineering industries in reducing the costs of production due to the introduction of high-speed steel is shown.

P. Goerens, *The Properties of Steels of High Quality* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1645-1659). Three categories of high-class steel are considered with regard to their physical and mechanical properties and composition, namely, nickel and nickel-chromium structural steels, steels which are utilised on account of magnetic and electric properties and properties of dilatation, and high-speed tool steel. The value of the tensile properties as an indication of the quality of the steels is discussed.

F. Rapatz and H. Pollack, *Black Fracture* (Stahl und Eisen, Nov. 27, 1924, vol. 44, pp. 1509-1514). The origin and causes of black fracture in steel are explained. The occurrence of black fracture is attributed to the presence of temper carbon, which separates out, when steels are cooled slowly from about 1000° C. to about 750° or if they are annealed for a long period at a temperature above 760° . The conditions for producing black fracture also require that the material shall be subjected to stress while at a temperature at which temper carbon is no longer soluble, except in the case of a very high graphite content, as in grey cast iron, which will show black fracture without being stressed. The peculiar forms of black fracture are due to differences of temperature in a piece during forging. A part of a forging that has remained cool will be subject to black fracture. Silicon favours the formation of black fracture, but chromium tends to eliminate it.

H. Brearley, *Defective Materials and Processes* (Lecture to Coventry Engineering Society: Brown Bayley's Journal). The author describes and illustrates types of defects and imperfections in steel.

M. Jacob, *The Heat Conductivity of Metals and Alloys of Importance in Technical Applications* (Chaleur et Industrie, November 1924, pp. 557-563). The heat conductivity of various metals and alloys varies considerably, and constitutes an important factor in their application, which is perhaps too often ignored by engineers and others. The question of what is the most suitable metal or alloy for certain specific purposes may be investigated from this point of view with at least as useful results, in many cases, as its strength, tenacity, hardness,

and other physical properties. The variations of, for example, aluminium, copper, &c., and such alloys as Constantan and Manganin, in their heat conductivities, indicate usefully the purposes for which they can most suitably be employed. In regard to iron and its alloys the same considerations hold good. At ordinary temperatures the heat conductivity of iron varies between 0.062 in the case of hard steel, to 0.207 for wrought iron, although authorities differ. Tables are given showing the varying conductivity of pig iron, malleable iron, steel, chromium steel, and nickel steel, at different temperatures, compiled from the latest sources of investigation.

A. Werner, *Thermal Expansion of Soft and Hard Steels* (Zeitschrift für Instrumentenkunde, 1924, vol. 44, pp. 315-320). The author has determined the coefficients of linear expansion of a number of soft steels of different composition and of steels hardened and then tempered for long periods at 150° to remove internal strain. The hardened steels all had a coefficient of 7 to 21 per cent. greater than the same steels unhardened. The actual values varied between 10.4×10^{-6} and 12.6×10^{-6} for soft steel and between 11.1×10^{-6} and 14.7×10^{-6} for hard steel at 20°. At the temperature of liquid air the coefficients fell to nearly one-half of the above values, and at 150° the minimum values were slightly higher than at 20°. An increase in manganese causes the coefficient of expansion to rise.

K. Honda and Y. Okubo, *The Measurement of the Coefficients of Thermal Expansion for Aluminium Alloys and Alloys of Nickel-Iron and Cobalt Iron* (Science Reports of the Tohoku Imperial University, Oct. 1924, vol. 13, pp. 101-107). With the addition of nickel to iron, the coefficient of expansion of iron decreases at first up to 18 per cent. of nickel and then increases to 25 per cent. Then it decreases rapidly up to 36 per cent. of nickel, and afterwards increases at first rapidly, and above 50 per cent. gradually up to the concentration of nickel. These results coincide with those of Guillaume, except the presence of the small minimum at 18 per cent. of nickel.

The coefficient of expansion of iron slightly decreases with the addition of cobalt; it reaches an inconspicuous minimum at 48 per cent. and afterwards gradually increases to the concentration of cobalt.

P. Hidnert and W. B. Gero, *Thermal Expansion of Molybdenum* (United States Bureau of Standards, 1924, Scientific Paper, No. 488). Expansion tests were made for various temperature ranges between room temperature and 750° C. on molybdenum ingots prepared from fine- and coarse-grained molybdenum powders and on samples swaged to various diameters. The results are presented in figures and tables.

P. Hidnert, *Thermal Expansion of Aluminium and Various Important Aluminium Alloys* (United States Bureau of Standards, 1925, Scientific Paper, No. 497).

Dilatometers (The Metallurgist: Supplement to the Engineer, Mar. 27, 1925, pp. 37-42). Various types of dilatometer are illustrated

and described, including the instrument devised by Chevenard and Andrew's dilatometer, as improved by W. T. Griffiths.

N. T. Belaiew, *Steel versus Lighter Alloys* (Institution of Aeronautical Engineers, 1924, Minutes of Proceedings, No. 13, pp. 15-28). The author briefly discusses the properties of the light aluminium alloys, and points out the importance of a correct fibrous structure in steels for aircraft construction.

J. B. Johnson, *Metals Used in World-Cruiser Airplanes* (Iron Age, Oct. 16, 1924, p. 994). The author gives brief details of the use of metal in the construction of the American aeroplanes which have recently completed a world cruise.

L. Aitchison, *Steel and Light Alloys as Engineering Materials* (Journal of the West of Scotland Iron and Steel Institute, Oct.-Nov. 1924, vol. 32, pp. 10-21). A comparison is made of the mechanical properties of cast iron, mild steel, nickel steel, nickel-chromium steel and aluminium alloys.

J. A. Mathews, *Austenite and Austenitic Steels* (Henry Howe Memorial Lecture to the American Institute of Mining and Metallurgical Engineers, Feb. 16, 1925). The first part of this lecture describes some of the physical characteristics of austenitic steels. Four types of steels are discussed: high-nickel steel containing 25 per cent. of nickel and upward, high-chromium steel, high-chromium nickel-steel in which chromium is usually higher than nickel, and high-chromium nickel-steel in which nickel is usually higher than chromium and to which a substantial amount of silicon has been added. The steels were subjected to various physical tests, including Rockwell and Brinell hardness, specific resistance, magnetic, thermal expansion, and microscopic; they were also tested for resistance to oxidation or scaling at high temperatures. In the second part of the lecture, which deals with the nature of austenite, the author summarises the work of other investigators, and records the results of his own observations and experiments. It is concluded that in all normally hardened medium or high-carbon steels, and in the usual engineering alloy steels, gamma iron, or austenite, is always present with the martensite. In a wide variety of alloy steels, notably those capable of hardening readily in oil, there is more austenite retained after the oil quench than after the water quench, in normal hardening. Austenite is a cause of increased permanence or retentivity in commercial permanent magnet steels and in many other alloy steels not used for magnets.

E. C. Bain and M. A. Grossmann, *The Nature of the Function of Chromium in High-Speed Steel* (Transactions of the American Society for Steel-Treating, Oct. 1924, vol. 6, pp. 430-442). The paper presents the results of an investigation of the effect of heat treatment upon the hardness, impact strength, and volume change of four high-tungsten steels of the following composition:

	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Carbon	0.59	0.55	0.67	0.60
Chromium	0.25	0.61	2.10	3.85
Tungsten ,	17.20	18.70	17.90	18.0

Chromium increases both the hardness and toughness of high-speed steel. It increases the amount both of austenite and of martensite formed at lower temperatures, and particularly the amount of austenite retained after quenching at 2400° F. It also serves to lessen the sharp concentration gradients throughout the steel. In the case of impact strength chromium acts to produce much greater uniformity of values. Tungsten alone in the steel quenched at very high temperatures causes a marked secondary hardness, which, however, is accompanied by brittleness. Chromium appears to cause the solution of tungsten into solid solution to proceed more rapidly. Chromium also reduces the oxidation and scaling of the steel enormously during heat treatment.

A. Hultgren, *Flakes or Hair Cracks in Chromium Steel, with a Discussion on Shattered Zones and Transverse Fissures in Rails* (Paper read before the Iron and Steel Institute, May 1925: this Journal, p. 113).

H. Redenz, *Wear Tests on Chromium Steel for Ball Bearings* (Stahl und Eisen, Dec. 8, 1924, vol. 44, pp. 1703-1708). Ball-bearing races of steel containing 1 to 1.2 per cent. of carbon and 1.2 to 1.9 per cent. of chromium were tested on an Amsler machine by rolling friction without lubrication. The amount of wear is dependent on the speed and the load, the specific wear being defined as the loss in weight in grammes $\times 10^{-6}$ per metre-kilogramme of work expended. The wearing strength of a material is the reciprocal value of the mean specific wear, or the frictional work in metre-kilogrammes required to produce a loss in weight of 1 milligramme. It was found that the normal wearing strength of well-annealed and hardened chromium steel suitable for ball bearings was 2800 to 3400 metre-kilogrammes. The results of the tests are fully set forth in diagrams.

W. H. Hatfield, *Recent Developments in Corrosion-Resisting Steels* (Paper read before N.W. Branch of Institution of Mechanical Engineers, Mar. 5, 1925: Engineering, Mar. 13, 1925, vol. 119, p. 319).

W. H. Hatfield, *The Possibilities of Stainless and similar Corrosion-Resisting Steels in the Chemical and Allied Industries* (Industrial Chemist, Mar. 1925). The author discusses the mechanical and acid-resisting properties of stainless steel and chromium-nickel steel. The behaviour of these steels when exposed to nitric, acetic, and other acids is shown.

W. H. Hatfield, *Recent Progress in the Metallurgy of Special Steels* (Revue de Métallurgie, Dec. 1924, vol. 21, pp. 562-563). An abstract, in French, of the paper read before the Empire Congress of Mining and Metallurgy, held at Wembley in June 1924, and since published in the "Proceedings" of that Congress, Part IV., pp. 81-95).

Nickel and its Alloys (United States Bureau of Standards, 1924, Circular 100). In this report the various physical properties of pure and commercial grades of nickel are described, together with a discussion of the relation of these properties to the composition and treatment of the material. The properties and applications of nickel and its commercially important alloys as Monel metal, nickel steels, ferro-nickels,

copper-nickel and chromium-nickel alloys, and other alloys containing nickel are dealt with. Attention is given to those alloys now finding wide industrial applications by reason of the electrical resistance, heat-resisting and acid-resisting qualities. An extensive bibliography on nickel and its alloys is included.

J. H. Andrew, *Special Steels* (Paper read before the Cleveland Institution of Engineers : Iron and Coal Trades Review, Mar. 13, 1925, vol. 110, pp. 427-428). The influence of nickel and chromium on carbon steel is dealt with. In a ferro-nickel alloy, with 10 per cent. of nickel, at a temperature of about 380°C . on cooling, so-called martensite is formed, the iron transforming to the alpha state. The author suggests that what happens at this change point is this : Above the change point nickel is in solution in the gamma-iron. The change point is due to the iron transforming into the alpha state ; and immediately it does so the nickel will be thrown out of solution. If the alloy were soaked for a prolonged time, the nickel would go into solution again and give rise to a soft alloy. Under normal conditions of cooling, however, the temperature is not sufficiently high for the nickel to be immediately redissolved, with the result that the nickel atoms hold the iron atoms apart from their normal or stable positions, thereby giving a material of comparatively low density. The nickel atoms, which immediately after the change exist as simple atoms dispersed throughout the iron lattice, will cause an expansion of this lattice, within the range of atomic distances, and the attractive forces of the iron atoms one for another will be greatly increased. These forces will then tend, in their endeavour to restore the iron atoms to their normal positions, to hold the included nickel atoms rigidly in position, and the whole structure will be that of a strongly braced system, displacement will be difficult, and actual rupture dependent upon the strength of the static forces present ; the material will be hard, and will have a high maximum stress. This suggested mechanism of the cause of the hardness is in no way related to the so-called "slip interference" theory, which relates to stable configurations or metastable states induced by cold-work. A similar effect will be produced upon quenching a high-carbon steel, the act of quenching bringing about the gamma-alpha change at a low temperature ; the carbide at this temperature will not, however, associate, so that on this basis a martensitic structure obtained in a carbon steel will consist of alpha iron in which the atoms are forcibly held apart by the entrapped dissociated carbide.

The author believes that the extraordinarily high Izod values associated with molybdenum steels, and the absence of impact brittleness in them, is largely due to the molybdenum increasing the solubility of the alpha iron for carbon.

It is suggested that the high remanent magnetism of a quenched high-carbon steel is due to the isolation by the carbide of iron of the innumerable small molecular magnets. This carbide serves as it were to keep these tiny magnets apart, and therefore to reduce the de-

magnetising effect of one upon another that would necessarily occur if all the little molecular magnets were touching one another. This suggestion is strengthened by the fact that the addition of tungsten, a very slightly paramagnetic element, greatly increases the remanent magnetism. Such a structure would be more difficult to magnetise on account of the slight insulation provided by the tungsten, but when once magnetised, would retain that state to a far higher degree.

A New Chrome-Nickel Alloy (Iron and Coal Trades Review, Feb. 27, 1925, vol. 110, p. 355). A new chrome-nickel alloy, known as "Emperor," has been introduced by Sutcliffe, Speakman & Co., Ltd. It is claimed to be superior to cast iron or steel for many purposes, such as hardening and annealing boxes and melting crucibles. It does not scale, warp, or crack, and has a long life at permanent working temperatures of 955° to 980° C., whilst at these temperatures also the tensile strength is the very high one of 13·3 tons per square inch.

High Chrome-Nickel Steels (Mining and Metallurgy, Nov. 1924, vol. 5, p. 542). The composition and properties of Rezistal, a high chromium-nickel steel produced by the Crucible Steel Co. of America, are outlined.

J. L. F. Vogel, *Notes on Alloy Metals used in Alloy Steels* (Journal of Society of Chemical Industry, Dec. 26, 1924, vol. 43, pp. 365-369 T.) A list is given of the metals and other elements employed in the manufacture of alloy steels, the specific gravities and melting points being also stated. Each metal is briefly described, with notes as to the source whence it is obtained, the form in which it is used for alloying with steel, and its particular influence on the properties of the steel product with which it is alloyed.

W. Oertel and E. Pakulla, *Note on Cobalt, Chromium, Tungsten, and Molybdenum Alloys* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1717-1720). Alloys of the class to which stellite belongs, in which iron is a minor constituent, were tested, in respect of their cutting efficiency, hardness at red heat, and resistance to corrosion. The higher the iron content the lower was the cutting efficiency and hardness. Both of these properties improved as the carbon was increased, the best cutting results being obtained with an alloy containing carbon 2·95, chromium 32·76, tungsten 15·21, cobalt 45·68, and iron 1·58 per cent. Also the higher the carbon, the more susceptible are the alloys to thermal treatment. The critical cutting efficiency when working on cast iron is lower than when working on nickel-chromium steel.

L. Guillet, *Cobalt and its Recent Applications* (Mémoires de la Société des Ingénieurs Civils, Oct.-Dec., 1924, pp. 697-711). After a brief introduction dealing with the properties and uses of cobalt, reference is made to the copper-cobalt alloys, and to the important group of permanent-magnet alloys consisting of cobalt-steel. The alloys used for magnets are the chromium-cobalt series and the chromium-tungsten-cobalt series. Their preparation, treatment, and magnetic properties are described and illustrated with tables and diagrams. The electrolytic deposition of cobalt on other

metals as a protective coating is also dealt with. The process is called "cobaltage."

R. Hohage and A. Grützner, *Vanadium in Structural Steels* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1713-1717). Steels containing 0.14 and 0.30 per cent. of vanadium were compared as regards tensile properties with plain structural steel, nickel-chromium and chromium-vanadium steels. Vanadium was found to raise the elastic limit and ultimate strength, and to lower the elongation, contraction, and notch toughness. The raising of the quenching temperature affects all these properties in the same direction respectively. Nickel-chromium steels are equal in strength to chromium-vanadium steels where small sections are concerned, but are superior if the section is heavy.

E. F. Cone, *High-Manganese Steel for Locomotives* (Iron Age, Oct. 2, 1924, vol. 114, pp. 824-825). The author describes briefly the composition and properties of a new high-manganese steel known as "hylastic," recently used in the production of cast steel locomotive frames and cross-heads. This high-manganese steel, so called because it contains more manganese than ordinary steel and much less than regular manganese steel, contains about 0.35 per cent. of carbon with the manganese between 1.60 and 1.80 per cent. The elastic ratio runs over 50 per cent. The steel, after being poured as castings, is subjected to a special heat treatment, the details of which are not obtainable.

E. H. McClelland, *Bibliography of Manganese Steel* (Forging, Stamping, Heat-Treating, Feb. 1925, vol. 11, pp. 49-53). The bibliography was prepared in the Carnegie Library, Pittsburgh. The entries are arranged in the alphabetical order of authors' names, and the reference of earliest date is that of Sir Robert Hadfield's paper of 1888.

R. H. Aborn, *Properties and Uses of Alloy Steels* (Iron Age, Mar. 5, 1925, vol. 115, pp. 685-687). The author has tabulated a great deal of useful information dealing with alloy steels, with reference to the influence of the alloying elements, composition, manufacture, and uses of the different steels and their relative advantages and disadvantages.

Crystallography ; Metallography ; Constitution.—P. Oberhoffer, *Primary Etching* (Stahl und Eisen, Feb. 12, 1925, vol. 45, pp. 223-224). Investigators have shown that there is a distinction between "clear" and "unclear" primary banded structure. The occurrence of a clear or unclear banded structure depends upon the development of the secondary structure and upon the compound effect of the primary etching reagent, which on the one hand brings out the differences of concentration within the mixed crystals and on the other exercises a secondary effect in differentiating between the ferrite and pearlite.

J. F. Harper, *Some Revelations by Deep Etching* (Transactions of the American Society for Steel Treating, Feb. 1925, vol. 7, pp. 237-243). The paper discusses the acid etching of forgings and castings for the purpose of inspecting the soundness of these materials. The author draws conclusions as to the advantages of this method of inspection.

Steels of varying analysis will show varying rates of solubility in the acid. Steel with heterogeneous composition will have a relatively rougher surface condition due to the differences in solubility of the different parts of the specimen. The same steel will vary in solubility when given different heat treatments. It is possible to a certain extent to identify the method of manufacture of steels of similar analysis due to their varying rates of solubility in the acid etch. The fact that there are differences in rates of solubility of these steels may lead to the explanation of the differences in physical properties of acid open-hearth, basic open-hearth, and electric furnace steels of apparently identical composition. Forgings made from chill-cast and sand-cast ingots show a marked difference in cleanliness and a slight difference in solubility. Incipient cracks, in all cases of defective steel examined, were intercrystalline and in all directions, although tending to be elongated in the direction of mechanical work. Cracks occurring in steel due to mechanical strain appear in a direction perpendicular to the stress in the material, and in all the specimens examined were intercrystalline.

B. Zschokke, *On Damascene Steel and Damascene Blades* (Revue de Métallurgie, Nov. 1924, vol. 21, pp. 635-669). Much confusion exists as to the methods employed in the East, in mediæval times, to manufacture the celebrated damascene steel so highly valued for sword blades. These have partly been elucidated by the work of P. P. Anossow, Tschernoff, N. T. Belaiew, and C. von Schwarz, and three main methods are now recognised as having been practised: the Indian, which was a direct crucible process; the Persian, a process of carburising the soft Indian iron known as "Wootz," and a simple annealing process carried out over long periods and out of contact with air, which confers the peculiar damascene structure. Very full descriptions of the technique of these processes are given, and a method employed by the author is also given, the various processes being, in each case, accompanied by photomicrographs of the distinctive structure. The hardness numbers of a variety of samples were investigated during the course of the research, which revealed that, for the attainment of results comparable with those of ancient times, materials of the most extreme purity are needed. The conclusion is reached that sword blades equal to the best oriental blades of former times can be made by modern methods from the best selected modern materials, but that, in view of the changed conditions of warfare, the increased cost is not commensurate with the object aimed at.

K. Harnecker, *Note on Damascene Steel* (Stahl und Eisen, Nov. 6, 1924, vol. 44, pp. 1409-1411). The literature on damascene steel is reviewed, reference being made in particular to Belaiew's work. A structure corresponding to the old damascene patterns is obtained by forging a hypereutectoid coarsely crystalline steel at temperatures below the E.S. line on the iron-carbon diagram. According to the conditions of annealing and the amount of forging, the primary network and needle structure can be more or less destroyed, and in place of the cementite

needles, while preserving their macroscopic outline, there appears a mass of spheroidal cementite, the occurrence of which is necessary to produce the damascene pattern. Etching shows up the cementite of the blade in white, while the dark etched patches of the pattern correspond to the original pearlite grains and retain the same composition. Both cast steel and cement steel may serve as the raw material for damascene steel.

J. D. Gat, *Preparation of Metallographic Specimens* (Blast-Furnace and Steel Plant, Dec. 1924, vol. 12, pp. 536-541). A statement of the procedure recommended to be followed for the preparation of satisfactory metallographic specimens for investigation.

G. F. Comstock, "*Dirty Steel*" under the Microscope (Iron Age, Apr. 23, 1925, vol. 115, pp. 1185-1188, 1244). The author deals with the precautions necessary in the preparation of specimens for the proper estimation of the degree of dirtiness or cleanness of steel. It is shown how various accidental surface appearances on a polished section may be mistaken for evidence of "dirt" embedded in the metal.

C. O. Burgess and J. R. Vilella, *Polishing of Iron and Steel Specimens for Metallographic Examination* (Transactions of the American Society for Steel Treating, Apr. 1925, vol. 7, pp. 486-493). The authors have studied the polishing of specimens, and have presented definite methods of procedure so as to eliminate the possibility of error arising in examination. The technique and proper preparation of metallographic specimens is discussed in detail. Photomicrographs are included showing the results of each polishing operation. A table of procedure is also incorporated in the paper.

R. G. Guthrie, *High-Power Magnification in Metallography* (Transactions of the American Society for Steel Treating, Jan. 1925, vol. 7, pp. 4-22). The author presents a number of photomicrographs produced at various magnifications, showing the effect of illuminating systems, &c., as well as the effect of high magnifications. Conical illumination is made use of for bringing out maximum detail. The magnifications used range from 1000 diameters up to as high as 12,500 diameters. Whatever the value inherently contained in high magnification may be, its true value is really a matter that will vary from one individual to another, and while a great discovery may not accrue from it, the author has found high-power photomicrography to be of great value in the examination and interpretation of specimens.

R. G. Guthrie, *Sample Preparation for High-Power Photomicrography* (Transactions of the American Society for Steel Treating, Mar. 1925, vol. 7, pp. 337-362). The author describes a method of preparing metallographic specimens for high-power photomicrography with which it is possible to eliminate or reduce to a minimum the amorphous film which usually covers the surface after polishing and which usually causes uneven etching. A paraffin polishing wheel is used which is coated with a soap solution carrying abrasive material. The final polish is obtained with a flannel wheel. The specimen is then etched and re-etched until

a satisfactory structure is obtained. The paper also includes photomicrographs showing various structures obtained from specimens of steel under both low and high power magnification ranging from 2300 to 15,000 diameters. The photomicrographs are presented in duplicate to show the fundamental differences between plain axial and conical illumination.

W. M. Mitchell, *Resolving Power, Magnification, and Enlargement* (Transactions of American Society for Steel Treating, May 1925, vol. 7, pp. 618-634). The paper describes in a theoretical way the considerations affecting the resolving power of the microscope. It includes a description of Abbe's theory of microscopic vision, and explains the importance of "numerical aperture," as introduced by Abbe. The maximum theoretical resolving power of the microscope is calculated for visual observations and for photomicrography for both dry and immersion objective systems. From these are determined the magnifications necessary to show full detail resolved by the objective when used visually or photographically. A discussion is given of the resolving power of the photographic plate as determined by the size of the silver grains in the emulsion. The use of enlargement to obtain large photographs at high magnification from small negatives, with the advantages offered by such photographs, is explained.

Microscopes for Metallographic Work (Engineering, Oct. 10, 1924, vol. 118, pp. 514-515). An improved type of micro-telescope is described, which is intended for high-class work in metallurgical research laboratories. Magnification up to 5000 diameters is possible. The apparatus is the design of F. Rogers, and has been brought out by F. Davidson & Co.

P. Chevenard, *On Simple Appliances for Revealing the Thermal Transformations of Steels and the Anomalies in Special Alloys* (Revue de l'Industrie Minérale, Mémoires, Mar. 15, 1925, pp. 107-130). A description of the apparatus employed at the School of Mines at St. Etienne, in the metallurgical lectures and courses. These include the investigation of the polymorphic and allotropic transformations of iron and steel by dilatometrical and other methods, heat treatment, and cooling curves generally, magnetic reversible transformations of ferro-nickels, and the anomalies of such alloys as invar and elinvar. The determination of the viscous deformations of steel at high temperatures is also dealt with.

E. P. Polushkin, *Determination of Structural Composition of Alloys by a Metallographic Planimeter* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). A new method is described for determining the structural composition of alloys. The area occupied by a constituent on a few representative photomicrographs of an alloy is measured by a planimeter, especially designed for metallographic work, and the volume and proportional weight of the constituent calculated. This method has been used for the determination of the structural composition of binary eutectics and other binary alloys

with known constituents ; also the composition of unknown constituents in binary alloys. Experiments have shown that the results are accurate enough to justify the application of the method to many problems in metallographic research instead of chemical analysis. The advantage of the method is the possibility of determining the amount of the constituents without separating them from the alloy ; their composition may also be determined if the ultimate chemical analysis of the alloy is known.

S. P. Rockwell, *Practical Metallography* (American Machinist, European and Colonial Edition, Nov. 15, 1924, vol. 61, pp. 487-492). Practical methods in the metallographic examination of steel are dealt with, and illustrated studies of various examples are given.

H. C. Knerr, *Heat Treatment and Metallography of Steel* (Forging, Stamping, Heat-Treating, Oct., Nov., Dec. 1924, vol. 10, pp. 385-392, 419-430, 459-466). The serial forms a practical course in the elements of physical metallurgy, describing all operations from the smelting of the ore in the blast-furnace, the manufacture of steel and the treatment of the finished products.

J. H. Andrew, *The Iron Carbon Diagram* (Journal of the Royal Technical College, Glasgow, 1924, No. 1, pp. 41-47). The author presents arguments to show that carbide of iron must exist as such when in solution in gamma-iron. The eutectoid occurring at 0.89 per cent. carbon theoretically should be regarded as a eutectoid of iron and a solid solution containing about 2.0 per cent of carbon. The molecular separation of the eutectoid constituents actually precedes their deposition. The carbide of iron goes into solution previous to the A₁ critical change, and it is this solution in alpha-iron which is responsible for the A₁ change in a silico-manganese steel.

A. Hayes and H. E. Flanders, *Structural Evidence of an Iron Carbide Eutectoid* (Transactions of the American Society for Steel Treating, Nov. 1924, vol. 6, pp. 623-629). The authors give the results of experimental work, which indicate that carbon existing in solid solution when the lower critical range is traversed very slowly, is distributed in the form of small rounded specks throughout the ferrite. This is considered as structural evidence of a eutectoid action. A mechanism for the formation of the ferrite shell about the primary carbon spots, in partially graphitised white iron, is described.

D. Hanson, *The Practical Importance of the Equilibrium Diagram* (The Metallurgist, Supplement to the Engineer, Feb. 27, 1925). An explanation, illustrated by simple examples, of the constitutional diagram of iron-carbon alloys and alloys of other metals is given showing the application of the diagram to the study of the constitution of alloys and of the critical changes occurring in them.

A. von Vegesack, *Graphic Representation of Ternary Iron-Carbon Alloys* (Stahl und Eisen, Mar. 26, 1925, vol. 45, pp. 458-461). Of the various graphic methods proposed or adopted for the study of the constitution of iron-carbon ternary alloys, that devised by P. Goerens is

recommended for general adoption as it permits an exact representation of all ternary compounds whatever carbon percentage may be chosen.

C. Benedicks, K. G. Lund, and W. H. Dearden, *Some Fundamental Factors for Obtaining Sharp Thermal Curves* (Transactions of the American Society for Steel Treating, Apr. 1925, vol. 7, pp. 445-456). The authors outline the guiding principles for obtaining more sharply defined thermal curves. The specimen should possess, as far as possible, a spherical form. A pear shape is to be recommended, as otherwise the heat conduction along the pyrometer exercises too strong an influence. If it is necessary to use a cylindrical specimen, then all edges should be rounded off. The thermo-junction must be located at the centre of the sphere; also, in the case of specimens of other shapes, it must be placed as centrally as possible. The obtaining of perfect contact between thermo-junction and specimen is most important. If this is not possible, and some insulating layer must be used, the junction should be strengthened so as to make a reasonably good contact. To obtain sharp heating curves, it is essential to avoid having the heating coil, or whatever is being used, in the neighbourhood of the specimen and thermo-junction.

E. Scheil, *Secondary Crystallisation of Steel* (Zeitschrift für anorganische Chemie, 1924, vol. 139, pp. 81-107).

F. Sauerwald, W. Schultze, and G. Jackwirth, *Criticism of Metallographic Heat-Etching* (Zeitschrift für anorganische Chemie, 1924, vol. 140, pp. 384-390). The development of a structure by heat-etching is not due to the action of a particular reagent, but to changes in the metal itself probably caused by volume changes due to heating and to the recrystallisation of the surface layer which has undergone a certain amount of cold-working during polishing. Prolonged annealing in a sodium-potassium chloride bath may lead to decarbonisation of the steel, and considerable changes in the crystal structure may be caused by impurities in the bath.

V. N. Krivobok, *Secondary Crystallisation in Iron-Carbon Alloys* (Transactions of the American Society for Steel Treating, Apr. 1925, vol. 7, pp. 457-458). The author has studied the rate of cooling through the granulation zone and zone of secondary crystallisation. The following conclusions are drawn: It is presupposed that when the temperature of cast hypo-eutectoid steel reaches the Ar₁ point, the residual austenite of strictly 0.90 per cent. carbon content is converted into pearlite. In other words, that all of the pro-eutectoid ferrite is ejected from solid solution (austenite). But such a complete ejection hardly ever occurs in the steels cooled in the way generally accepted in the foundry practice. Part of the ferrite is rejected, part of it remains in solution. The boundaries between grains seem to be the places where the rejection of ferrite is facilitated. Such ferrite forms a continuous meshwork structure, enveloping the outlining of the original austenitic micrograins. The inner structure of the grain is sorbitic, containing more ferrite than is called for by pearlite.

Such partial rejection of ferrite occurs under the condition of rapid cooling through the granulation and secondary crystallisation zones. If the cooling is somewhat slower more ferrite is rejected. The ferrite at the grain boundaries will, by virtue of its presence, induce the rejection of the additional ferrite near or at the grain boundaries. This ferrite may: (1) either join the ferrite at the boundaries, rendering the latter thicker, or (2) be located between the cleavage planes of the grain, forming "shoots" of excess ferrite. These "shoots" or "lamellæ" of ferrite will be projected toward the interior of the grain, gradually fading away. Should the cooling be slower the rejected ferrite will assume more perfect forms and appear on polished sections of the steels as the "cleavage" or "Widmanstätten" structure. In an extreme case such a structure will occupy the whole of the grain. It is believed that under conditions of very long and slow cooling the cleavage character of the structure will still be preserved. The "ultimate" structure, if we can imagine one, is pictured as approaching the cleavage structure, rather than the network. By the expression "ultimate" structure, the author means the structure that can be attained under the conditions excluding the possibility of either spheroidising of cementite or the graphitisation of the sample.

F. Wever and P. Rütten, *The Mixed Crystal Gamma-Iron-Carbon* (Mitteilungen aus dem Kaiser-Wilhelm Institut für Eisenforschung, 1924, vol. 6, pp. 1-6). A series of austenitic manganese steels was prepared, with carbon rising regularly from 0.30 to 1.90 per cent. A method for the exact measurement of lattice parameters of substances is described and the parameter of pure nickel was determined afresh. Using the lattice for nickel as a basis of comparison, the parameters of the manganese steels were then determined, and from these the specific volumes were calculated according to the two possible hypothesis: (1) that the carbon intrudes into the lattice by substitution of itself for metal atoms, or (2) that it is wedged in the spaces of the lattice. The latter theory is in agreement with the observations made, thus confirming the view that carbon does not replace metal in the lattice. It is suggested that the carbon searches out the spot within the lattice where, in consequence of its small atom volume, it produces the least disturbance in the stability.

I. Obreimow and L. Schubnikow, *Production of Single Crystals of Metals* (Zeitschrift für Physik, 1924, vol. 25, pp. 31-36). An apparatus for the production of single crystals of metals is described. Solidification takes place in a small container with an opening at the top and at the bottom, the one at the bottom being no larger than a fine capillary tube into which the metal enters. The container is kept under vacuum to prevent formation of blowholes, and the body of metal in it is at first maintained just above melting-point while the capillary tube is cooled, so as to form a centre of solidification from which solidification afterwards extends to the whole mass, so that a single crystal is obtained. The cross-section of the capillary has to be varied for different metals.

K. Heindlhofer and F. L. Wright, *Density and X-Ray Spectrum of Hardened Ball Steel Tempered at Various Temperatures* (Transactions of the American Society for Steel Treating, Jan. 1925, vol. 7, pp. 34-53). The X-ray diffraction method was applied to reveal the nature of a transformation occurring during the tempering of quenched ball steel. This transformation is evidenced by density and hardness measurements and by the microstructure. The X-rays show that austenite is invariably present in the quenched specimens and that this austenite transforms at temperatures between 200° and 260° C., and that during this transformation the formation of an intermediate hard product is indicated. This intermediate product will simultaneously be subjected to tempering due to the prevailing temperature.

K. Heindlhofer, *Crystal Structure of Hard Steel* (Physical Review, Oct. 1924, vol. 24, pp. 426-438). With an X-ray spectrometer the spectra were determined for 0.80 and 1.31 per cent. carbon steels, both in coarse and fine martensitic conditions. The same lines were found as in the spectrum of carbon-free iron, but were less intense. Martensite has a body-centred lattice like that of α -iron, but the lattice is contracted about 0.4 per cent. on a side and is distorted, but the distortion disappears after heating at 260° C. for thirty minutes. Martensite is thought to be a mixture of a solid solution of carbon in iron, the carbon atoms replacing the iron atoms, and of finely dispersed cementite.

F. Sauerwald and G. Jackwirth, *Nature of Martensitic Structure of Steel* (Zeitschrift für anorganische Chemie, 1934, vol. 140, pp. 397-398). From an examination of annealed and quenched polished steel specimens it is concluded that the appearance of martensite is caused by slipping induced by the stresses set up during quenching, and that the characteristic lines of the structure are the edges of the slip plane.

F. F. Lucas, *The Microstructure of Austenite and Martensite* (Transactions of the American Society for Steel Treating, Dec. 1924, vol. 6, pp. 669-691). The author has investigated the structural characteristics of austenite and martensite. A 2.65 per cent. carbon iron was used in the experiments. The application of high-power metallography, which corroborates the results of X-ray analyses, is described, and a number of photomicrographs at magnifications from 175 to 5600 diameters is included in the paper. The ultimate crystal form of austenite is the cube. Two, three, or four lines or cleavage planes, directly traceable to the geometry of an octahedron, may be developed in the austenitic grain, depending on the orientation of the grain. Austenite decomposes into martensite; it may also transform directly to troostite without passing through the martensitic stage; it may develop a "line" or cleavage structure which appears to be decomposition along crystallographic planes to troostite, with the elimination of excess carbide, or it may precipitate ferrite in perfect cube form. Austenite satisfies the general conception of a solid solution. No substantial evidence is found for the existence of a third allotropic form of iron. Alpha-iron and iron carbide are incompatible, and when the

opportunity affords they tend to separate. Gamma-iron converts readily to the alpha state, and may form in tiny cubic particles, and these particles persist and grow, forming the ferrite of lamellar pearlite, Martensite appears to consist of an acicular crystal-like substance, which forms along the octahedral crystallographic planes of the austenite.

Martensite etches readily with picric acid, but shows a marked selectivity for the central rib to etch much more deeply than the rest of the needle. Martensite also stains readily with boiling sodium picrate, and the central rib stains a little darker, if anything, than other parts of the crystal. Deep etching with picric or nitric acid fails to develop etching pits, but does bring out a line structure. The width of these lines is of the order of 0.000006 inch or less. Martensite is often found with a decidedly granular appearance. This may be due either to partial decomposition to troostite or to the fact that the needle showing this structure is sectioned on a plane almost parallel to the plane of the line structure described above. Martensite develops twins, which often have a common twinning plane with the parent austenite. Martensitic development was found always to be confined to areas of uniform orientation of the austenite, and in no case was a martensitic needle found to cross a twinning plane of the austenite. This of itself constitutes substantial evidence of the arrangement of martensite along crystallographic planes, and it also shows how persistent the original crystallographic planes must be.

J. H. Whiteley, *Observations on Martensite and Troostite* (Paper read before the Iron and Steel Institute, May 1925 : this Journal, p. 315).

B. D. Enlund, *On the Structure of Quenched Carbon Steels* (Paper read before the Iron and Steel Institute, May 1925 : this Journal, p. 305).

K. P. Grigorovitch, *Nature and Hardness of Metals* (Messager technico-économique russe, Apr.-May, 1923, Nos. 127-130 ; Revue de Métallurgie, Extraits, July 1924, vol. 21, p. 319). The author considers that the needle-like appearance of martensite and the zig-zag lines of electrolytic iron are due to optical effects caused by internal stresses. Annealing electrolytic iron or hardened steel, with martensitic structure, removes these internal stresses, and the true structure of the metal can be revealed by etching.

G. Moressée, *Heat and Atomic Motion* (Revue Universelle des Mines, Apr. 15, 1925, vol. 6, pp. 66-80), and *The Strength of Materials, a Resultant of Atomic Forces* (ibid., pp. 89-93). Two articles, the object of the first being to provide data and pave the way for the second. In the preliminary investigation a theoretical and mathematical analysis is made of atomic motion in metals, and a calculation attempted of their characteristic infra-red waves. In the light of modern physics, temperature is but a function of the mean atomic or molecular mechanical energy. Most metals are bi-atomic. The dynamic conditions of an atom are therefore indicated by the temperature, equated with a number of known coefficients. When the radius of rotation, or the rate of

rotation are known, the unknown factor is easily deducible. The frequency is, of course, the infra-red wave-length. Einstein and Lindemann have both calculated η for various metals, and, amongst them, iron. Their results are given, and compared with those calculated by the author from his data. Before definite conceptions can be entertained, certain apparent discrepancies between classical crystallography and the new science of crystal lattice structure revealed by X-ray analysis have to be cleared away. Ultimately the whole question of the tensile strength of metals and of the elastic limit resolves itself into an investigation of variation with temperature. The two problems to be solved are: (1) the determination of the load corresponding with the elastic limit, and (2) the variations which occur at varying temperatures, and therefore the correction which has to be applied in considering the load value at different temperatures. For iron the elastic limit (pure iron being, of course, taken as the basis) at absolute zero is found to be 2300 kilogrammes per square centimetre. At 15° C. it becomes 1400 kilogrammes, and at 1027° C. (= 1300° absolute) it falls to 368 kilogrammes per square centimetre. Formulae are given for the determination of the elastic limit of semi-hard steel at various temperatures. The other metals discussed in the same connection are aluminium, copper, and lead. The practical utility of the research is the guidance it affords in heat-treating and working metals in such operations as forging and rolling.

H. A. Lorentz, *The Motion of Electricity in Metals* (May Lecture before the Institute of Metals, 1925). Modern ideas on the motion of electricity in metals are reviewed.

R. J. Anderson and J. T. Norton, *X-Ray Evidence versus the Amorphous-Metal Hypothesis* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). The evidence offered in the paper that amorphous metal probably does not exist is of a direct nature, and is afforded by X-ray diffraction effects given by a number of metals and alloys when polished, cold-worked, and annealed. A considerable part of the experimental work was carried out with substantially pure aluminium and duralumin, but many of the observations made on these materials were checked by similar observations on copper, iron, tin, zinc, lead, mild steels, and brass. The conclusion is drawn, on the basis of X-ray evidence, that metals are fragmented on cold-work and polishing, and not amorphised.

W. T. Astbury and Kathleen Yardley,[†] *Tabulated Data for the Examination of the 230 Space Groups by Homogeneous X-Rays* (Philosophical Transactions, Aug. 20, 1924, vol. 224, pp. 221-257). The paper summarises the conclusions of mathematical crystallographers in a form immediately useful to workers using homogeneous X-rays for the analysis of crystal structures. Given a crystal belonging to a particular system, the X-ray worker can determine, with two exceptions, to which space-group the crystal belongs, by means of the number of molecules per unit cell and the abnormal spacings found.

R. Glocker and E. Kaupp, *The Fibrous Structure of Electro-Deposited Metals* (Zeitschrift für Physik, 1924, vol. 24, pp. 121-139). An X-ray examination of a number of electro-deposited metals shows a fibrous structure whose axis of growth is perpendicular to the surface. The formation of fibrous structure is largely dependent upon the kind of solution.

E. J. Janitzky, *An Assumption as to the Cause of the Change of Body-Centred Alpha-Iron to Face-Centred Gamma-Iron* (Transactions of the American Society for Steel Treating, Dec. 1925, vol. 6, pp. 728-731). The author offers a mathematical explanation of the causes for the change of iron, when heated, from a face-centred to a body-centred orientation.

G. R. Levi, *The Study of Crystalline Substances by X-Rays, and its Chemical Applications* (Giornale di Chimica Industriale ed Applicata, Feb. 1925, vol. 7, pp. 78-89). A description of the principles underlying X-ray examination of crystals, metals, and other substances. The apparatus required is illustrated, and the necessary manipulation described in detail, with accompanying diagrams and photographs. The principal methods are those of Laue, of which there are several modifications, Bragg's method, and the Debye and Scherrer method. A new mode of X-ray examination has also been devised by Schiebold-Seeman. Each of these methods gives distinctive photographs and affords means of ascertaining the fundamental structure of materials and the atomic arrangement of the constituent particles. A short bibliography is appended.

H. H. Lester, E. C. Herthel, W. Mendius, and W. V. Ischie, *Using X-Rays to Detect Hidden Dangers in Plant Equipment* (Chemical and Metallurgical Engineering, Oct. 20, 1924, vol. 31, pp. 619-622). The results are given of an investigation of defects in castings by means of X-ray examination.

H. H. Lester, *X-Ray Tests Applied to the Problems of the Steel Foundry* (Transactions of the American Society for Steel Treating, Nov. 1924, vol. 6, pp. 575-605). Numerous photographs are given of typical defects in steel castings as revealed by X-ray examination.

L. C. Breed, *Examination of Steel by X-Rays* (Blast-Furnace and Steel Plant, Nov. 1924, vol. 24, pp. 517-518). A short report on the spectrometer equipment at the Government Arsenal at Watertown, Mass., is given. The present installation has a nominal capacity of 300,000 volts, and it is expected ultimately to raise the limits to 500,000 volts, so that it will be possible to examine steel 5 or 6 inches in thickness.

W. W. Coblenz and C. W. Hughes, *Ultra-Violet Reflecting Power of Some Metals and Sulphides* (U.S. Bureau of Standards, Scientific Paper No. 493). The authors present data on the ultra-violet reflecting power of the sulphides of metals (lead, molybdenum, iron, and antimony) having a high metallic lustre. The materials examined were the natural minerals—galena, molybdenite, pyrites, and stibnite. It is shown that, in contact with the metals which have a low reflecting

power in the ultra-violet and in the visible spectrum, followed by a high reflecting power in the infra-red, the sulphides of these metals have a high selective reflection in the ultra-violet, followed by a lower and more uniform reflection in the infra-red spectrum. Data are given also on the reflecting power of graphite, duralumin, and magnalium.

M. Bamberger, O. Einerl, and J. Nussbaum, *Investigation of Commercial Ferro-Silicon* (Stahl und Eisen, Jan. 29, 1925, vol. 45, pp. 141-144). Two grades of ferro-silicon were selected for the experiments, one with 73.1, the other with 48.3 per cent. of silicon. By mixing these in different proportions, samples with various silicon percentages were obtained, the average proportion being about 50 per cent. silicon. The iron-silicon diagram is plotted and compared with the diagrams of Guertler and Tammann and of Kurnakow and Urasow. Etched sections were also prepared for studying the structure. A new constituent, disilicide of iron (FeSi_2), was discovered, which crystallises in flakes and is extremely brittle. The impurities giving off phosphuretted hydrogen exist in an apparently concentrated form in the eutectic in which the iron silicide crystals are embedded. On exposure to the atmosphere the alloy disintegrates into loose crystals, and in disintegrating it gives off a considerable quantity of poisonous gas.

Magnetic Properties of Iron and Steel.—S. Evershed, *Permanent Magnets* (Paper read before the Institution of Electrical Engineers, Mar. 19, 1925). This paper is the sequel to the paper by the same author published in 1920, and together the two papers give a complete account of the modern theory and practice of magnet making. Carbon steel is now seldom used for permanent magnets. Tungsten magnet steel has the same character as carbon magnet steel, but half the carbide of iron is replaced by carbide of tungsten, the total content of carbon remaining unchanged. The effect of replacing part of one solute substance by another is to increase the magnetic coercive force from rather less than fifty to little more than seventy, but when cobalt is used instead of tungsten the coercive force is increased to 180. Cobalt steel withstands demagnetising forces much more effectively than tungsten steel. If two permanent straight magnets, one of tungsten steel and the other of cobalt steel, are subjected to demagnetising forces equal to 20 per cent. of their coercive force, the tungsten magnet would lose 14 per cent. of its strength, but the cobalt magnet would only lose 3 per cent. Tungsten steel, however, is still more generally used than cobalt steel on account of its much lower cost. Many experiments were made on the loss of coercive force in all kinds of permanent magnets. In a cobalt magnet, for example, the initial coercive force was 180, but after 4.4 years it had fallen to 161.8. This continued falling off in the coercive force of hardened steel is attributed to the passage of carbide molecules out of solution. Immediately after the hardening, the coercive force decreases by about 7 per cent. in the first hundred hours, but after a year the rate of deterioration appears to settle down to a

small steady value. Heat treatment of course requires very careful attention. If tungsten steel be heated to any temperature between 750° and 1214° C., and kept at this temperature for an appreciable time before hardening, its magnetic properties are weakened in proportion to the length of time the temperature is maintained. The deterioration proceeds most rapidly when the temperature is 950° . At 1200° the spoiling of the steel goes on very slowly, the coercive force falling only 0.4 unit per hour. At 1240° , which is only 26° above the danger zone, restoration of the coercive force takes place at the rate of fifteen units a minute. The possibility of making magnets of complicated shapes by casting from molten metal and then suitably heat-treating them is considered.

G. Hannack, *Magnet Steel, with Special Reference to the Relation between Carbon Content and the Magnetic Properties* (Stahl und Eisen, Oct. 9, 1924, vol. 44, pp. 1237-1243). Measurements were made on eight hundred specimens of tungsten magnet steels in which the proportion of carbon varied from 0.549 to 0.703 per cent. The average composition of the steel specimens otherwise was: Tungsten 5.40, manganese 0.32, silicon 0.18, phosphorus 0.03, sulphur 0.02 per cent. It was found that a maximum induction of 17,000 was obtained in the carbon-tungsten steel containing 0.55 per cent. of carbon; with carbon = 0.67 per cent. the maximum induction was 16,000. The remanence also falls with increasing carbon content, the 0.55 carbon steel showing a remanence of 12,100 and the 0.65 carbon steel showing one of 11,450. The coercive force rises as the carbon is increased. In short, in a tungsten-carbon steel a definite variation in the magnetic properties occurs according as the carbon percentage is varied, and a variation in the carbon has a greater influence than a variation of any other constituent. The same rule holds good, though in a less marked degree, with chromium-carbon magnet steels.

J. Würschmidt, *Magnetic Methods of Testing, with Special Reference to Permanent Magnets* (Stahl und Eisen, Dec. 18, 1924, vol. 44, pp. 1727-1734). The magnetometric method, the Koepsel method, and the ballistic method of testing magnet steel are critically examined; the most suitable being found to be the ballistic, with or without yoke. For the testing of permanent magnets a method similar to that of Koepsel has been worked out with the aid of Hartmann and Braun's magnetising apparatus, the performance of which is simple and presents several advantages.

W. B. Kouwenhoven, *Magnetic Tests on A.S.T.M. Drills* (Proceedings of American Society for Testing Materials, 1924, vol. 24, Part II., pp. 635-650). For the investigation fifty-two high-speed drills $1\frac{1}{2}$ inch in diameter were used. The object of the magnetic tests was to determine if it is possible to classify drills magnetically in accordance with their heat treatment and other features, and to discover by magnetic analysis those drills which had been properly treated. A comparison of the results of drilling tests with those of magnetic and hardness tests shows

that certain drills that did well in the drilling test have widely different magnetic and hardness properties. The reason for this is not known. If a single group of first quality drills is selected, and the proper limits chosen, it is a comparatively simple matter to eliminate the other drills by means of the magnetic tests, and the magnetic tests are more successful in picking out the good drills than are the hardness tests.

A. V. de Forest, *Magnetic Determination of the Elastic State* (Transactions of the American Society for Steel Treating, Dec. 1924, vol. 6, pp. 653-668). In this paper are described the relations between stress and certain magnetic properties. A method of alternating current magnetic measurements is described which gives a critical determination of the elastic limit. The relation between elastic and fatigue properties is illustrated by means of the Jenkin model and the magnetic results are interpreted from that point of view.

R. L. Sanford, *Effect of Stress on the Magnetic Properties of Steel-Wire* (United States Bureau of Standards, 1924, Scientific Paper, No. 496). The work described is part of a more extended investigation on non-destructive methods of testing wire rope. Data are given in terms of magnetic reluctivity showing the effect of stress on the magnetic properties. It is found that the reluctivity, which is a linear function of the magnetising force for pure homogeneous materials, no longer shows such a linear relationship when tension is applied to the wire. It is shown how two components of the material, differing only as regards stress condition and each following the linear relationship, can be combined to give the results found by experiment. This method of analysis seems to be capable of further development and extension into other fields of magnetic analysis.

S. W. J. Smith, A. A. Dee, and W. V. Mayncord, *Magnetism of Annealed Carbon Steels* (Proceedings of Physical Society, 1924, vol. 37, pp. 1-14). The residual moment of a magnetised rod of annealed steel of given dimensions is shown to be reversed when the temperature is raised to 180°C . This appears to be due to the laminated structure of the iron-iron-carbide eutectoid, and the effect disappears when that structure is destroyed. It is suggested that the method of experiment would furnish useful indications of the structure of steel samples and of the effect of their heat-treatment.

K. Daeves, *Influence of Grain-Size on the Losses in Dynamo and Transformer Sheets* (Stahl und Eisen, Oct. 16, 1924, vol. 44, pp. 1283-1286). In silicon steel sheets the influence of previous cold-working of any degree cannot be removed by any kind of heat treatment, even in material with silicon as low as 0.2 per cent. This accounts for the difference in the losses of sheets of different shape, and also for the differences between the centre and edge of a sheet. The influence of carbon, phosphorus, manganese, and silicon on the losses within certain limits was determined. With carbon rising from 0.04 to 0.11 per cent. the loss increases regularly by 0.1 watt kilogramme for every 0.04 per

cent. of carbon. With silicon rising from 3·7 to 4·2 per cent. the loss diminishes by 0·05 watt kilogramme for every 0·4 per cent. of silicon, but increases slightly at higher silicon percentages. Phosphorus up to 0·02 per cent. slightly increases the loss, but beyond that point actually causes an improvement. Manganese between 0·05 and 0·3 per cent. does not appear to exercise any influence. The influence of carbon on the magnetic properties of transformer sheets is so important, and the quantities of carbon to be taken into account are so minute, that the author considers it will be necessary to devise new analytical methods for determination of carbon and for distinguishing between the infinitesimal quantities of graphite, cementite, pearlite, and hardening carbon.

T. D. Yensen, *Magnetic Properties of the 50 per cent. Iron-Nickel Alloy* (Journal of the Franklin Institute, Mar. 1924, vol. 199, pp. 333-342). The author has studied the magnetic properties of two nickel-iron alloys containing 50 per cent. and 78 per cent. nickel respectively. Diagrams are plotted, showing the very remarkable magnetic properties of these alloys, and the author's previous experience with iron-silicon alloys is confirmed, namely, that the magnetic properties of materials in general are very susceptible either to minute variations in composition or small variations in heat treatment, or both, and results obtained with a single series of alloys prepared in one way and annealed according to one method, may give only the slightest indication of properties obtainable with the same alloys prepared and treated in a slightly different way.

Sir Robert Hadfield, *Steel and Electrical Engineering* (Electrician, Nov. 28, Dec. 5, 1924, vol. 93, pp. 606-609, 637-639). The author deals with the development of alloy steels and their uses in the electrical industry.

F. B. H. White, *Nickel and Electrical Engineering* (Electrician, Nov. 28, 1924, vol. 93, pp. 610-619). The author discusses the development and uses of nickel alloys in the electrical industry.

P. Dejean, *Some Considerations Respecting the Magneto-Chemistry of Ferro-Magnetic Alloys* (Revue de Métallurgie, Mémoires, June 1924, vol. 21, pp. 339-340). Well-defined magnetic saturation points can be found corresponding with Fe_3Ni and Fe_2Co , hence the measurement of such saturation can throw a light on the chemical composition of nickel-iron and cobalt-iron alloys. The coercive force of a steel is often considerably increased when carbides, gases, or other impurities pass into solution in the ferrite, and here again measurements can be made to ascertain the amount of such impurities. In particular, the amount of occluded oxygen can be found by such means.

Specifications.—*British Standard Sections of Steel Fishplates for British Standard Flat Bottom Railway Rails* (British Engineering Standards Association, 1924, Report No. 47A).

Interim British Standard Specification for Cast Iron Piston Ring Pots

(*Sand Cast and Chill Cast*) for *Automobiles* (British Engineering Standards Association, 1924, Report No. 5004).

British Standard Specifications for Railway Rolling Stock Material, Part 5. Copper Plates, Rods, Tubes and Pipes, and Brass Tubes (British Engineering Standards Association, 1925, Report No. 24).

Dimensions for British Standard Whitworth (B.S.W.) Bright Hexagon Bolts, Set-Screws and Nuts, Split-Pins, Washers and Studs (British Engineering Standards Association, 1924, Report No. 190).

Dimensions for British Standard Fine (B.S.F.) Bright Hexagon Bolts, Set-Screws and Nuts, Split-Pins, Washers and Studs (British Engineering Standards Association, 1924, Report No. 191).

British Standard Specification for Marine Flanges (British Engineering Standards Association, 1924, Report No. 3022).

W. J. Corbett, *Inspection Standards for Steel Castings* (Iron Age, Jan. 8, 1925, vol. 115, pp. 115-119). The inspection standards adopted by the Electric Steel Founders' Research Group for the inspection and testing of steel castings are outlined.

Corrosion.—*The Deterioration of Structures in Sea-Water* (Department of Scientific and Industrial Research London, 1924). This is the fourth (interim) report prepared by the Committee of the Institution of Civil Engineers. The present work contains, amongst others, the following reports :

Report on the Corrosion of Iron and Steel in the Landing Stage at Weston-super-Mare, by E. J. McKaig and J. Newton Friend.

Report on the Corrosion of Strained Metals in Artificial Sea-Water, by J. Newton Friend.

W. P. Wood, *Causes and Controlling Factors in the Corrosion of Iron and Steel* (Transactions of the American Society for Steel Treating, Mar. 1925, vol. 7, pp. 321-336). The acid and electrolytic theories of corrosion are compared and the work leading up to the substantiation of the electrolytic theory is reviewed. The inaccuracy of acid tests is emphasised. The controlling factors of corrosion are listed and their effects and importance discussed. A brief review of the author's work in connection with the effect of light upon corrosion of iron is included in the paper.

Corrosion (Industrial and Engineering Chemistry, Apr. 1925, vol. 17, pp. 335-392). A symposium of papers on the subject of the corrosion of metals was presented to the Division of Industrial and Engineering Chemistry of the American Chemical Society, at a meeting at Baltimore, April 1925. The following seven papers among others were presented :

W. D. Bancroft, *Corrosion in Aqueous Solutions* (Paper read before the American Chemical Society, Apr. 1925). The author outlines the theoretical points which have been brought out in the study of corrosion during the past twenty-five years, with special reference to their bearing on electrolytic corrosion. The electrolytic theory is endorsed by the author. The value of further research is emphasised, particularly on the

effect of oxygen supply to the corroding metals, and of films, and on the development of a satisfactory accelerated test.

F. N. Speller, *A Study of Corrosion Factors and the Electrochemical Theory* (Paper read before the American Chemical Society, Apr. 1925). The various factors which affect the progress of corrosion and the mechanism by which they act are enumerated.

W. G. Whitman and R. P. Russell, *The Acid Corrosion of Metals* (Paper read before the American Chemical Society, Apr. 1925). The authors discuss the effect of oxygen and velocity in the acid corrosion of metals. It is shown that variation of these two factors causes great difference in the rate of corrosion. The quantitative results are given for several of the common useful metals. The effect of oxygen in solution is shown to be different for different metals and different solutions. The effect of oxygen is usually to increase corrosion, but it may diminish it where films are formed or passivity induced. Its effect is not so marked in the presence of oxidising acids as in non-oxidising. Velocity was shown to have large effect where oxygen is an important factor in the corrosion, and to influence the removal of films in cases where these are formed. There is much variation in the effect of velocity under different conditions.

U. R. Evans, *Oxygen Distribution as a Factor in the Corrosion of Metals* (Paper read before the American Chemical Society, Apr. 1925). The paper contains a detailed discussion of the corrosion of zinc and iron by electric currents set up by differential aeration. The formation of films is given close study, their thickness being estimated by their interference colours. It is shown that the position of corrosion on iron, whether localised in one area or pitted over the whole surface, or evenly distributed, is due to electric currents set up by difference in the distribution of dissolved oxygen. According to the author, the oxygen acts by the formation of surface films, which tend to make the areas over which they form cathodic, thus protecting them from corrosion. The corrosion is concentrated on the anodic areas, which are not covered by films. The effect of whirling the test-pieces on the formation of films is also described.

W. E. Pratt and J. A. Parsons, *The Practical Use of Laboratory Corrosion Tests* (Paper read before the American Chemical Society, Apr. 1925). The type of corrosion data obtained by the use of typical acid materials is tabulated, and conclusions are drawn as to the inadequacy of present information and the desirability of additional work on tests and standardisation of methods. The possibility and value of standardising laboratory corrosion tests are shown, and a description is given of an apparatus and method of testing which have proved satisfactory.

J. W. Shipley, I. R. McHaffie, and N. D. Clare, *Corrosion of Iron in Absence of Oxygen* (Paper read before the American Chemical Society, Apr. 1925). It is shown that, when oxygen is not present, the rate of corrosion of iron is proportional to the hydrogen-ion concentration down

to pH of 9.4, and that below this corrosion ceases. The submerged corrosion of iron embedded in impervious clay is found to be due to the buffer action of the clay in conditions sufficiently acidic to evolve hydrogen, and to the lowering of hydrogen overvoltage by the thin film of solution on finely subdivided clay in contact with the metal. The location of pits is determined by the constituents of the iron, but, if oxygen is present, the migration of ferric hydroxide to cathodic areas perpetuates and enlarges them. If the non-corrodible constituents are sufficiently cohesive, as is the case in grey cast iron, graphitic softening rather than pitting is produced.

W. R. Whitney, *Corrosion of Iron* (Paper read before the American Chemical Society, Apr. 1925). The author describes the corrosion of steam-turbine blading by steam and water at high velocity. The results show conclusively that most of the wearing away formerly attributed to erosion is really due to corrosion, during which corrosion products are carried away physically.

W. G. Whitman, R. P. Russell, and G. H. B. Davis, *The Solubility of Ferrous Hydroxide and its Effect upon Corrosion* (Journal of the American Chemical Society, Jan. 1925, vol. 47, pp. 70-79). It has been pointed out that the effect of protective films in the corrosion of iron may be largely regulated by the solubility of ferrous hydroxide. The authors have carried out experiments to determine the solubility of ferrous hydroxide in pure water and also in salt solutions, with the hope of further explaining the effect of various salts upon the rate of corrosion. It is shown that the precipitation of colloidal ferric hydroxide in salt solution has apparently no direct connection with the rate of corrosion.

W. M. Thornton and J. A. Harle, *The Electrolytic Corrosion of Ferrous Metals* (Paper read before the Faraday Society, Feb. 16, 1925).

U. R. Evans, *Surface Abrasion as a Potential Cause of Localised Corrosion* (Paper read before the Institute of Metals, Mar. 1925). Experiments were carried out to ascertain whether the electric currents set up by the local abrasion of the surface layers on metals is capable of causing serious localised corrosion. Where the corrosion product is loose and flocculent, the abraded portion is often cathodic, and no localised corrosion need be feared; where the corrosion product is a thin, highly protective film, the abraded place will be the anode, and the currents set up to tend to concentrate corrosion upon it. But whilst localised electro-chemical corrosion due to mechanical removal of the corrosion product is thus perfectly possible, it seems that in most cases the corrosion will only occur if the abrasion is sufficient to produce also mechanical erosion of the metal itself. The conclusion reached, therefore, represents a compromise between the "corrosionist" and "erosionist" views. The effect of localised removal of high temperature oxide films has also been studied, and the currents produced between two electrodes of the same metal (one greasy, one ungreasy) have been measured.

C. M. Kurtz and R. J. Zaumeyer, *The Corrosion of Iron Alloys by*

Copper Sulphate Solution (Paper read before the American Electrochemical Society, Oct. 1924). The author describes an investigation in which about four hundred alloys prepared from electrolytic iron were subjected to the copper sulphate test. Of the alloys tested, those containing chromium appeared the most resistant. Silicon was also found to be very resistant. Nickel is effective provided there is 6 per cent. or more of chromium present. If nickel alone is alloyed with electrolytic iron, it does not begin to resist corrosion until the nickel content reaches at least 45 per cent. With certain alloys corrosion resistance was greater after heating the samples to redness and quenching in water. Tests at 93° C. gave practically the same results as those at room temperature.

W. E. Erickson and L. A. Kirst, *Tests for Grading Corrosion-Resisting Alloys* (Paper read before the American Electrochemical Society, Oct. 1924). It is pointed out that the copper sulphate test used by Kurtz and Zaumeyer does not differentiate between alloys of high resistance and those of only moderate resistance. The experiments described by the authors were undertaken in the hope of separating these alloys into several groups according to their resistance to corrosion. The alloys were tested with solutions of copper sulphate, silver nitrate, platinum chloride, gold chloride, and palladium chloride.

C. Hoerhans, *Comparative Corrosion Tests of Hot Galvanised Sheet Iron and Sheets Galvanised by Spraying* (Zeitschrift für Metallkunde, Feb. 1925, vol. 17, p. 69). Seven specimens of sheet iron, each $200 \times 200 \times 2$ mm., were galvanised by the Meurer spraying process, the number of coatings ranging from one to five. A corresponding number of specimens were hot galvanised, and one pair was exposed respectively to tap-water, sea-water, soda solutions, sulphuric acid solutions, and atmospheric air. In all cases the sprayed specimens withstood the corrosive attack much better than the hot galvanised specimens.

W. Lulofs, *Tests for Corrosion of Boiler Material at High Pressure* (Electrical Times, Dec. 1924, vol. 66, pp. 689-690). Tests on small steel bars cut from boiler tubes were made by immersing the bars in pure distilled water and in water containing salts in various degrees of solution. The bars were exposed to the action of the water in a boiler for twelve hours, first at a pressure of sixteen atmospheres and then at a pressure of forty atmospheres. The loss in weight though small was greater under the higher pressure.

U. R. Evans, *Water-Line Corrosion of Iron and Steel, with Special Reference to the Action of the so-called Inhibitors of Corrosion* (Journal of the Society of Chemical Industry, Apr. 10, 1925, vol. 44, pp. 165-169T). Water-line corrosion includes two distinct phenomena, which are separately discussed by the author: 1. Corrosion on the area above the water-line, which becomes wetted through splashing or intermittent alterations of water-level, and thus becomes exposed to air and water simultaneously. This is a situation favourable for rapid corrosion, but

where the rust is produced as a uniform blanket over the whole of the wetted surface and continues to adhere, it may interfere with the passage of dissolved oxygen to the metallic surface, and thus slow down the corrosion. Cast iron undergoes softening, but the changes in it may escape notice until it is tested with a knife. A description is given of a specimen of cast iron embedded in the foundations of Westminster Bridge (built in 1862) and taken out in 1924. 2. Corrosion concentrated at or just below a stationary water-line. In many fresh and salt waters the zone just below the water-line is singularly free from corrosion, since it becomes ennobled through the formation of an adherent oxide film which in some cases is visible; in such waters, it is the area rather lower down which suffers corrosion, as the result of electric currents flowing between these unaerated portions as anode and the aerated portions at the water-line as cathode. However, if "inhibitive chemicals," such as sodium carbonate or potassium chromate, which tend to reduce the total corrosion through the formation of a protective film, are added to waters containing chlorides, corrosion may then set in at the water-line, because there the close adhesion of the protective film is most likely to fail. Such substances—although reducing the total corrosion as indicated by loss of weight—may often increase the real damage, by causing the corrosion to be localised at the water-line (and sometimes at other places lower down), so that the metal becomes perforated more quickly than if no inhibitor were present; the loss of weight is valueless as a means of conveying an estimate of the damage, the eye being a better judge of this than the balance. Potassium chromate is perhaps a safer inhibitor than sodium carbonate, but neither should be added to a corrosive water, until experiments have been performed to ensure that the corrosion is prevented altogether, and not merely concentrated upon a limited area.

C. Benedicks, *Action of Hot Wall: a Factor of Fundamental Influence on the Rapid Corrosion of Water Tubes and Related to the Segregation in Hot Metals* (Paper read before the American Institute of Mining and Metallurgical Engineers, Feb. 1925). The author discusses the formation of deep pits in condenser and boiler tubes of brass and steel. A purely physical effect must influence the problem, namely, the action of the hot wall, implying that from air-containing water a gas-phase is precipitated on the hottest points of the wall—in a similar way to the precipitation from moist air of a liquid phase on the coldest bodies in contact with it. This local precipitation of air, will, on definite points, necessarily prevent the water from exerting its cooling power on these points, and the result will be a considerable temperature increase there. This local superheating, under given circumstances, can give rise to a local, purely thermal pitting of the metal wall; further, if chemical action comes into play, the local superheating will cause local corrosion of the wall. The author describes experiments by which he is able to produce deep pits under air bubbles attaching themselves to thin nichrome ribbon heated by a current of electricity while immersed in

water saturated with air. The author proposes to de-aerate water to prevent pitting by introducing a series of electrically heated coils of resistance wire into the supply pipes and draining off the air which bubbles up from these hot wires into suitable domes. The influence of "hot wall effect" on segregation in ingots is also discussed.

R. Binaghi, *Graphititis (Spongy Disease)* (*Annali di Chimica Applicata*, 1924, vol. 14, pp. 71-102). The tendency of iron pipes to become fragile and easily perforated, without, however, losing their shape, has been variously termed graphititis, spongy disease, &c. A review is made of experimental and theoretical investigations in the past to explain the physical and chemical cause. A general consideration of all conditions involved indicates that graphititis is not the result of the decomposition of graphite, but is due to the solvent action of water on the iron of the pipes. The spongy product is the residue of graphite, iron oxides, &c., remaining undissolved. This solvent action is due to chemical, electrochemical, or autoelectrolytic action. The process is favoured by a low state of carburisation of the iron. A bibliography of literature of the subject is appended.

K. H. Logan, *Soil Corrosion Investigation* (Paper read before the American Foundrymen's Association, Oct. 1924). The relation of soils to the corrosion of pipes has been studied. From experiments it is concluded that rapid pitting of lead, iron, and steel may sometimes occur where stray currents are absent, a fact that has often been disputed; that there apparently are several causes of soil corrosion, and, that in certain soils serious corrosion of iron and steel occurs within two years. In so far as the conclusion may be warranted from short time tests, the results indicate that no one of the commonly used pipe materials tested is generally superior to the others under all soil conditions. On the other hand, the tests seem to show that the pipe material best suited to one soil condition may give a relatively poor showing under a different soil condition.

Kröhnke, *Corrosion of Iron Pipes* (*Wasser und Gas*, 1924, vol. 14, pp. 294-296). Various types of corrosion of iron pipes are described.

R. E. Wilson and W. H. Bahlke, *Special Corrosion Problems in Oil Refining* (Paper read before the American Chemical Society, Apr. 1925). The authors describe special corrosive problems encountered in the refining of petroleum, and methods of combating corrosion. Corrosion in the "fire and steam" distillation of crude oils is shown to be caused principally by the hydrolysis of magnesium chloride in the salt which is present, producing hydrochloric acid in the condensed water. Nickel-chromium or high chromium steels and some special bronzes are shown to be resistant to this corrosion. In coking distillation and in cracking stills, the most severe corrosion occurs in the parts of the apparatus above 600° F. and is due to hydrogen sulphide and other sulphur compounds. Under these conditions the stainless steels, aluminium, and calorised iron are resistant.

W. J. Müller, *The Passivity of Metals, with Special Reference to Iron*

(*Zeitschrift für Elektrochemie*, Sept. 1924, vol. 30, pp. 401-416). The anodic passivation of iron in sodium sulphate solution is demonstrated experimentally. The formation of the layer of ferrous sulphate is seen by the darkening of the electrode, while passivity is accompanied by a brightening appearance.

Metallurgical Education and Research.—H. C. H. Carpenter, *Metallurgical Education of University Rank in Great Britain* (*Revue de Métallurgie*, Dec. 1924, vol. 21, pp. 600-601). An abstract, in French, of the paper read by the author at the Empire Mining and Metallurgical Congress held at Wembley in June 1924, and since published in Part V. of the "Proceedings" of that Congress.

W. Rosenhain, *Metallurgical Research in England* (*Iron Age*, Apr. 2, 16, 1925, vol. 115, pp. 975-978, 1014, 1129-1131). An illustrated description is given of the buildings and equipment of the National Physical Laboratory, Teddington, and the nature of the metallurgical research work carried out.

CHEMICAL ANALYSIS.

Analysis of Iron and Steel.—G. Batta, *Some Remarks on the Subject of Pig Iron Analyses* (Chimie et Industrie, Feb. 1925, vol. 13, pp. 195–198). Judging composition from the fracture is not only misleading, but a grave source of error. Photographs and analyses of special instances are given, showing how accepted views as to the composition by grade differ from the actual composition as ascertained by analysis. Composition, moreover, will vary considerably in regard to the same pig iron at different periods during casting; conclusions and results drawn, for example, from one pig, are not, very often, properly applicable to the whole cast. This applies more especially to the silicon content. Certain dangers in sampling are also to be guarded against. Comparative analyses of sifted and unsifted drillings vary greatly in carbon. Hints are given for chemists not familiar with these facts, and suggestions are made for avoiding errors due to such causes.

The Analysis of Grey Iron Foundry Alloys (Foundry Trade Journal, Nov. 13, 27, 30, Dec. 11, 1924, vol. 30, pp. 416, 445–447, 464, 503–504). The continuation of a series of articles describing methods for the analysis of pig iron, ferro-silicon, spiegel, silico-spiegel, and ferro-manganese.

Standard Methods for the Analysis of Metals in Austria. Analysis of Cast Iron (Oesterr. Chemiker Zeitung, 1924, vol. 27, pp. 135).

Delavenna, *Note on Improvements Effected in the Method of Estimating Carbon by the Nolly Process* (Revue de Métallurgie, Dec. 1924, vol. 21, pp. 758–764). The method described consists in igniting, by means of an electric spark, the sample to be analysed, the operation being carried out in a water-cooled flask filled with pure oxygen. The sample is previously mixed with a known quantity of lead dioxide. The carbon dioxide formed is absorbed by caustic soda solution and titrated in the ordinary way. The method is rapid and accurate.

G. H. Stanley, *Determination of Carbon in Steel* (Journal of the South African Chemical Institute, 1924, vol. 7, pp. 3–8). The author describes a rapid direct combustion method for the estimation of carbon in steel.

Koch, *The Analysis of Steel* (Zeitschrift für angewandte Chemie, 1924, vol. 37, pp. 623–624). The author points out the necessity of removing SO_2 or SO_3 in the determination of carbon in steel. Pumice wet with chrome-sulphur acid is excellent for this purpose.

L. A. Congdon, F. J. Brown, and R. K. Friedel, *Critical Studies on Methods of Analyses: Carbon* (Chemical News, 1924, vol. 129, pp. 253–257). A standardised sample of steel containing carbon 0.61 per cent.

was analysed by the following methods : direct combustion in a Shimer platinum crucible of the carbon after solution of the steel in potassium copper chloride solution ; direct combustion of the steel ; and wet combustion of the carbon both with and without previous separation of the iron by the copper chloride process. Individual trials by each process show varying results, but the authors place the methods in the order given above according to their accuracy.

C. Holthaus, *The Simultaneous Determination of Sulphur and Carbon in Steel, Pig Iron, and Ferro-Alloys by Combustion in a Current of Oxygen* (Stahl und Eisen, Nov. 27, 1924, vol. 44, pp. 1514-1518). The apparatus and the method for carrying out the determination of sulphur and carbon simultaneously are described. For the rapid determination of sulphur, the sulphur dioxide formed by combustion at 1050° in a stream of oxygen is estimated. For determining the carbon by combustion the sulphur dioxide is absorbed in chromic acid, and the carbon dioxide is passed into N/2 sodium hydroxide, and the sodium carbonate formed is titrated with an equivalent solution of hydrochloric acid. The apparatus is arranged to allow the carbon and sulphur to be determined simultaneously.

L. Lindemann, *Determination of Chromium and Vanadium in Steel* (Industrial and Engineering Chemistry, 1924, vol. 16, pp. 1271-1272).

L. Lindemann, *The Determination of Chromium and Vanadium in Alloy Steels* (Metal Industry, Oct. 31, 1924, vol. 25, p. 431). The method described is founded on numerous estimations. The principles involved are based upon the oxidation of chromium from the tri-valent to the hexa-valent condition in dilute sulphuric acid solution, by means of persulphate and permanganic acid, the reduction of the chromic acid and the vanadic acid by means of a standard ferrous sulphate, the estimation of the slight excess of ferrous sulphate by means of a standard chromic acid solution followed by a titration of the vanadyl to vanadic acid by means of a standard potassium permanganate solution.

L. W. Spring and E. W. Hutchison, *A Quick Qualitative Test for Nickel Steel Bars or Alloy Steel Bars containing Nickel without their Removal from the Stock Racks* (Transactions of American Society for Steel Treating, May 1925, vol. 7, pp. 657-659). The paper describes a rapid qualitative test for nickel in steel bars containing nickel. It has been found that 0.05 milligramme of nickel per cubic centimetre is the smallest quantity of nickel that can be determined with certainty by the method described. For a 1.25 per cent. nickel steel it becomes necessary to dissolve 4 milligrammes of the steel to obtain a satisfactory precipitate with the dimethylglyoxime.

O. L. Maag and C. H. McCollam, *Rapid Determination of Molybdenum in Steel* (Industrial and Engineering Chemistry, May 1925, vol. 17, p. 524). A description of a method for the rapid determination of molybdenum as practised in the laboratory of the Timken Roller Bearing Co., Canton, Ohio.

G. Watson Gray and C. D. Garbutt, *Estimation of Phosphorus in the*

Presence of Vanadium (Paper read before the Iron and Steel Institute, May 1925 : this Journal, p. 395).

H. Mitschek, *Determination of Manganese in Special Steels and Ferro-Alloys containing Cobalt* (Chemiker Zeitung, 1925, vol. 49, pp. 25-27).

G. G. Reissaus, *The Volumetric Determination of Molybdenum in Molybdenite and Ferro-Molybdenum* (Metall und Erz, 1924, vol. 21, pp. 118-120). The volumetric methods of Freidheim and Euler and of Pisani are unsatisfactory. Details are given for a modified procedure, based on Zn reduction and KMnO_4 titration.

W. J. King, *The Volumetric Determination of Small Quantities of Carbon in Tungsten by Combustion* (Journal of the American Chemical Society, Mar. 1925, vol. 47, pp. 615-621). Modifications in the volumetric method for the determination of carbon in tungsten by combustion are presented. An absorption apparatus is described whereby carbon dioxide is precipitated and filtered as barium carbonate in the hot solution and the filtered solution titrated without transferring to a second vessel. The addition of 15 per cent. of ethyl alcohol and 10 per cent. of barium chloride to the standard 0.01 N solutions of barium hydroxide and hydrochloric acid is recommended. The use of a mercury seal and flexible plunger, providing for a closed combustion train during analysis, is shown. A series of analyses of a standard sample of tungsten powder containing 0.052 per cent. of carbon shows that, in samples varying in weight from 0.016 gramme to 0.288 gramme, the maximum error in the percentage of carbon found is 0.006 and the average error is 0.0026.

A. E. Stoppel, C. F. Sidener, and P. H. M.-P. Brinton, *The Idiometric Determination of Vanadium* (Journal of the American Chemical Society, Nov. 1924, vol. 46, pp. 2448-2453). The conditions have been established under which vanadium can be conveniently and accurately determined iodimetrically. The necessity for a preliminary oxidation is pointed out, and the most reliable method for this oxidation is given. It is shown that moderate amounts of molybdenum do not interfere when proper precautions are taken. Tungsten renders the results somewhat low, and uranium interferes decidedly with the method.

K. Swoboda, *Determination of Phosphorus in Ferro-Vanadium* (Oesterr. Chemiker Zeitung, 1924, vol. 27, pp. 110-113).

Analysis of Ores.—A. Stadeler, *Critical Investigation of the Methods of Determining Silica in Ores, Slags, Additions, and Fireproof Building Materials* (Stahl und Eisen, Nov. 20, 1924, vol. 44, pp. 1477-1481). The determination of silica, in ores, slags, and similar material can best be carried out in platinum or porcelain dishes. Glass beakers are not so suitable. After evaporation of the liquid used for solution the residue should be heated for 1 hour at 130°C . to render it insoluble. Seeing that silica is soluble in considerable quantity in hydrochloric acid and water especially in presence of alkalis, a second evaporation of the filtrate and washing water is essential in the case of high silica content. For the

determination of silica in materials which are insoluble in hydrochloric acid, treatment with alkaline carbonate is desirable. With the exception of fluorine other constituents have no effect on the silica determinations, but the presence of fluorine involves the use of a special method.

C. E. Sims and B. M. Larsen, *Determination of Ferrous Iron in Materials containing Metallic Iron* (Industrial and Engineering Chemistry, Jan. 1925, vol. 17, pp. 86-88). The method described is for the accurate determination of ferrous iron in substances containing both metallic and ferric iron, and is of importance for studies of iron ore reduction. The metallic iron is removed by copper sulphate solution, the precipitated copper is then removed by an alkali cyanide solution, and the residue, consisting of ferrous and ferric oxides and gangue, is dissolved in hydrochloric acid out of contact with air and the solution is titrated directly for ferrous iron. The metallic iron in the filtrate from treating with copper sulphate solution can be determined, and the total iron run on a separate sample, and the ferric iron can then be found by difference. The method is not accurate in the presence of large amounts of ferrous sulphide.

E. J. Virgin, *The Determination of Sulphur in Pyrites Ores* (Statens Provvnings-Anstalt, Stockholm, Report No. 22, 1924, 41 pp.). At the Swedish Government Testing Institute, Stockholm, the usual standard methods for determining moisture and sulphur in pyrites ores have been subjected to a critical investigation. Great variation has often been found in the results of analyses of the same sample of pyrites at different laboratories, and some improvement in the methods of analysis appears to be necessary. A method has been devised and adopted as the Swedish-Norwegian official method for the determination of sulphur and moisture in pyrites, and full particulars are given in both the Swedish and English languages.

W. Manchot and F. Oberhauser, *New Method for Determining Iron with Permanganate in Hydrochloric Acid Solution* (Zeitschrift für anorganische allgemeine Chemie, 1924, vol. 138, pp. 189-194).

N. A. Tananaev, *The Gravimetric Determination of Iron and the Rapid Dissolving of Ignited Ferric Oxide* (Zeitschrift für anorganische Chemie, 1924, vol. 136, pp. 184-188).

A. McMillan and W. C. Ferguson, *Electrometric Titrations, with Special Reference to the Use of Titanous Chloride for Ore Analysis* (Journal of Society of Chemical Industry, Mar. 27, 1925, vol. 44, pp. 141-142T.). Titanous chloride was used as the titrating reagent in the analysis of ores containing iron and manganese, the iron being present in the ferrous and ferric conditions. The iron in brown hæmatite can be determined very quickly by this method. The ore is dissolved in hydrochloric acid and titrated directly with titanous chloride electrometrically. The percentage of iron found was 69.53, while titration with dichromate gave 69.37 and 69.42 per cent. iron. The method is also applicable for the determination of ferrous iron in the presence of ferric iron.

E. Rousseau, *Separation of Nickel and Iron from Chromium by*

Electrolysis (Chimie et Industrie, Feb. 1925, vol. 13, pp. 199-201). Nickel is difficult to estimate when large amounts of chromium are present. In electrolysis as ordinarily practised, the oxygen which evolves from the anode oxidises the chromium to ammonium chromate and prevents the deposition of the nickel. The chromium should therefore be removed first. When, however, citrate and oxalate of ammonium are present in an excess of ammonia, and a current of 6 to 8 volts and 5 to 8 amperes is employed at 80° or 90° C. the deposition proceeds rapidly, as the evolved gas facilitates the diffusion of the ions. Processes based on this principle are described. They are, moreover, applicable to alloys of chromium, cobalt, and iron. The cobalt is, however, deposited more slowly than the nickel.

W. Claus, *Electrometric Analysis* (Giesserei Zeitung, Jan. 1, 1925, vol. 22, pp. 7-12). Describes apparatus and methods for carrying out analyses by the measurement of the conductivity of electrolytes.

Analysis of Fuel.—E. Goutal, *The Determination of the Carbon Percentage of Fuels, Organic Substances, Refractory Products, Alloys, &c.* (Chaleur et Industrie, Aug. 1924, pp. 409-412). A summary of methods and apparatus specially designed for the estimation of carbon, with notes of certain precautions which it is necessary to observe in the conduct of such analyses.

E. Goutal, *Determination of Carbon in Fuels, Organic Substances, Refractories, and Alloys* (Colliery Guardian, Nov. 7, 1924, vol. 128, pp. 1189-1190). An English translation of the above paper.

C. de la Condamine, *The Analysis of Solid Fuels* (Chaleur et Industrie, June 1924, vol. 5, pp. 304-308). A complete method is given for the proximate and ultimate analysis of fuel. In regard to the usual proximate analyses for moisture, volatile matter, and ash, certain precautions are suggested. The ultimate analysis includes the determination of carbon, hydrogen, nitrogen, sulphur, phosphorus, and oxygen (by difference). Tests are also given for fusibility of ash, coking or agglutinating power, and the degree to which the fuel has been oxidised. Tables of the fusing point of ash in various French coals are given.

H. Bahr and W. D. Heide, *Rapid Determination of Sulphur, especially in Coal* (Zeitschrift für angewandte Chemie, 1924, vol. 37, pp. 848-851). The determination of sulphur in coal by the alumino-thermite process is described.

Analysis of Gas.—C. de la Condamine, *Analysis of Producer-Gas and the Estimation of Carbon Monoxide* (Chaleur et Industrie, Sept., Oct., Nov. 1924, pp. 478-486, 526-537, and 586-590). The proper working of a producer can only be secured and maintained by a careful and constant determination of the composition of the gases. Many of the manipulations are difficult, and methods of sampling, &c., require special precautions. The subject is dealt with in minute detail and

fully illustrated. The sections are devoted respectively to sampling; the apparatus employed (Bunté, Orsat, &c.); the reagents and their preparations; and the mode of conducting the analytical operations.

S. W. Parr and F. E. Vandaveer, *The Analysis of Fuel Gas* (Illinois University, Engineering Experiment Station, 1924, Circular No. 12). The procedure for fuel gas analysis is outlined, and the modified form of Orsat apparatus and the Illinois apparatus are described. The manipulation of the Illinois apparatus is given in detail. The report includes a review of the methods employed in gas analysis, embodying also investigation work as to the efficiencies of these methods.

L. F. Flesher, *New Absorbent for Oxygen in Gas Analysis* (Journal of the American Chemical Society, Dec. 1924, vol. 46, pp. 2639-2647). An alkaline solution of sodium hyposulphite containing sodium anthrahydroquinone β -sulphonate as an absorbent for oxygen is recommended.

M. Moeller, *Technical Gas Analysis by Platinum Catalysis* (Zeitschrift für technische Physik, 1924, vol. 5, pp. 591-596). The author has devised an apparatus for the indication of the percentages of CO_2 , CO , H_2 , and SO_2 in furnace gases. An electrically heated platinum wire is stretched in a small chamber through which the gas is allowed to stream. Changes in the resistance of the wire are produced by the change of its temperature due to the different heat conductivities of the gases, and these changes of resistance, compared with the resistance of another platinum wire in a separate air chamber, are determined by means of a Wheatstone bridge.

R. Wigginton, *Automatic Gas Analysis* (Fuel, Sept. 1924, vol. 3, pp. 336-341). A description of recent forms of recorders for the automatic estimation of CO_2 in flue gases.

C. S. W. Grice and W. Payman, *The Bone-Wheeler Gas Analysis Apparatus* (Fuel, July 1924, vol. 3, pp. 236-249). An illustrated description of the Bone-Wheeler apparatus is given. It is generally accepted as the standard gas analysis apparatus, being accurate in use and suitable for the analysis of simple or complex gas mixtures of widely varying compositions. The use of the apparatus is described in detail.

De la Condamine and Laffargue, *A Study of the Appliances Designed for the Estimation of Carbonic Anhydride in Industrial Gases* (Annales des Mines, 1925, No. 3, vol. 7, pp. 169-227). The first instalment of an exhaustive investigation of the theory and practice relating to CO_2 estimations, with graphs showing amounts absorbed by varying strengths of soda and other solutions, and detailed descriptions of the types of apparatus employed.

Analysis of Refractories.—*Fireclays—A Method of Analysis* (Foundry Trade Journal, Oct. 16, 1924, vol. 30, p. 342). The principle on which the method described is based is that aluminium nitrate on heating is converted to the insoluble oxide, while calcium and magnesium nitrates

remain practically unaffected. In the ordinary methods of analysis the alumina is precipitated with ammonia, redissolved and precipitated again. The process is not only tedious, but there is a great risk of the large precipitate occluding small percentages of lime and magnesia, thus rendering the analysis inaccurate.

E. P. Barrett and F. W. Schroeder, *Analysis of Aluminous Silicate Refractories* (Journal of American Ceramic Society, 1925, vol. 8, pp. 68-71). A description of a method of analysis of aluminous silicates is given.

NOTICES OF RECENT BOOKS PRESENTED TO THE LIBRARY.

ANDERSON, R. J. "*Metallurgy of Aluminium and Aluminium Alloys.*" 8vo, pp. xxxi + 913, with 295 illustrations. New York, 1925 : Henry Carey Baird & Co., Inc. (Price \$10.00.)

This volume forms a comprehensive treatise on the metallurgy of aluminium and aluminium alloys, covering the subject from the mining of bauxite to the uses and applications of the metal and its alloys. The work will be of great help to metallurgical engineers, and in particular to those occupied in the design and manufacture of automobiles, aircraft, and other machinery where lightness is a special consideration. Considerable attention has been given to the preparation of alloys for casting and working; melting practice is discussed on the basis of the author's extensive investigations carried out in the U.S. Bureau of Mines. The best methods of melting, together with descriptions of the principal types of furnaces, are treated in detail. Literature in a handy form on the subject of the metallurgy of aluminium and its alloys is somewhat scanty, and the present work has been prepared to fill the need for an up-to-date treatise. The chapters on soldering and welding, on working, spinning, and machining, will be of much use to the metal worker.

BUDGEN, N. F. "*Cadmium : Its Metallurgy, Properties, and Uses.*" With Foreword by Professor Thomas Turner, M.Sc., A.R.S.M., F.I.C. 8vo, pp. xiv + 239. London, 1924 : Charles Griffin & Co., Ltd. (Price 21s.)

Cadmium, which is about the rarest of all the common metals, is comparatively little known, though the properties of cadmium have been known to scientific men for many years and its existence for more than a century, but the metal has never hitherto found extensive application in the industries. It is suitable for use for several purposes where lead, tin, and some other metals are now utilised, but on account of its rarity and consequent high price its application in this direction is at present not an economic possibility. Cadmium sulphide offers good prospects for an increase in consumption, and there is also a hopeful field of application in the manufacture of anti-friction metals, while the use of cadmium alloyed with copper for telephonic, telegraphic, and power transmission purposes is largely on the increase. As there is little literature on the subject, save that contained in technical periodicals and transactions of scientific societies, chiefly German, it is to be hoped that the present volume, which constitutes a comprehensive digest of all available information collected from widely scattered sources, will serve a useful purpose in propagating a general knowledge of the metal cadmium, which in time will undoubtedly become of increasing usefulness.

"*The Chemical Engineering and Chemical Catalog, 1925.*" Being a catalogue of heavy and fine chemicals, raw material, machinery, plant, and equipment applicable to production industries : standardised, condensed, 1925—i. 2 R

and cross-indexed. 4to, pp. 260. Compiled, with the co-operation of leading British manufacturers, by Leonard Hill, 173 Fleet Street, London, E.C. 4. (Price 21s.)

This work is intended to form a standard text-book of reference for chemical, consulting, and contracting engineers, works managers, and others whose business it is to prepare specifications and to purchase plant, equipment, and material for use in the manufacture mainly of consumable products. Avoiding the use of advertising factors, such as artistic display and comparative claims of quality, the publishers have made every endeavour to furnish in place thereof precise data, descriptive illustrations, tables of sizes and capacities, and information concerning the specific uses of materials and plant. The convenience and advantage of a work which comprises the names and particulars of all the plant and material available will justify the large number of cross-indices and the apparent superfluous repetition of the same names. In short, the catalogue is a compilation in a condensed form of the catalogues of manufacturers, edited and arranged in such a way as to give as much detail as possible to those seeking for information on sources of supply.

"The Engineer's Year-Book for 1925." Being a compendium of the modern practice of civil, mechanical, electrical, marine, gas, aero, mine and metallurgical engineering. Compiled and edited by H. R. Kempe and W. Hanneford Smith. 8vo, pp. 2974. London, 1925: Crosby Lockwood & Son. (Price 30s.)

As in previous issues of this well-known work of reference, in addition to the usual general revision by the editors in chief, the numerous associate editors and contributors have subjected their respective sections to a thorough revision. Important alterations and additions have been made in order that modern engineering practice may be standard throughout the volume. New data and tables have been introduced, old matter has been rearranged, and much information which had been rendered obsolete by advances in practice has been excised. In particular, the section relating to electrical engineering and electric traction has been extensively revised, and mention should also be made of the important new sections dealing with bridges and bridge-work, and with "The Calculus" and "Curves."

FIELD, S., and S. R. BONNEY. *"The Chemical Colouring of Metals and Allied Processes."* 8vo, pp. xix + 264. London, 1925: Chapman & Hall, Ltd. (Price 10s. 6d.)

It is difficult to trace the origin of the modern methods of colouring metals. The art of bronzing was first developed in France, but up to 1828 only one colour of bronze was known to the trade, the verde-antique, which could be produced in different shades. After that date new methods of bronzing were invented by various French and Italian artists, and later the colouring of many other metals by different methods developed into an important industry. The numerous methods of chemical metal colouring do not lend themselves to easy classification, but generally speaking there are four different principles on which the art of colouring is based: (1) Mechanical methods, in which a definitely coloured material is applied to the surface of the metal; (2) thermal methods, by which a coloured film, usually an oxide film, is produced by the application of heat; (3) chemical methods, depending upon the interaction of the metal with some chemical substance by which a film is produced; and (4) electrolytic methods, in which films of metals, oxides, or even other compounds are obtained by

electrolytic action. The practice involved in the colouring of metals by these various methods is described.

Practical directions are necessarily brief, and the personal element of the operator must come largely into play, as the best results depend upon the artistic temperament, and in all cases of practical work artistic processes defy accurate description. In view of the wide extension of metal manufactures and of the numerous applications of metals, the need for their protection, and the desire for decorative effects, a simple treatise on the subject like the present one is highly useful.

GILLETT, H. W., and S. L. MACK. "*Molybdenum, Cerium, and related Alloy Steels.*" 8vo, pp. 299. New York, 1925: The Chemical Catalog Company, Inc. (Price \$4.)

This book is based on the thesis that a given alloy steel is a member of a class rather than any special entity, and that with due regard to the necessary heat treatment it is often possible to produce, by combination or substitution of different alloy elements, several chemically different steels which are practically interchangeable for the same engineering application. Many metallurgists in recent years have followed this idea, as, for example, Aitchison in his "Engineering Steels." That book, however, is confined to the alloy steels universally available to the engineer, but in America conditions make it desirable that molybdenum steel should also be discussed from this point of view. The United States possesses large reserves of molybdenum, while the home supply of other useful alloying elements is restricted, either by nature or by economic conditions. Molybdenum is now known to be one of the most potent alloying elements for steel, and it is destined to take its place beside nickel, chromium, and vanadium as an alloying element. The object of this book is to enable it to take that place, by making better understood the possibilities and limitations of the element. The largest gaps in the knowledge concerning molybdenum steel appear to be its effect on endurance and toughness, and also its influence on the properties of transverse specimens. The experimental work described in the book has been carried out with a view to filling those gaps. The work involved the investigation of both molybdenum and cerium, and the title has been chosen to express this fact, though cerium is not classed as being necessarily a true or useful alloying element.

THOMPSON, F. C. "*A Course of Metallurgy for Engineers.*" 8vo, pp. 240, with numerous photographs, photomicrographs, and diagrams. London, 1925: H. F. and G. Witherby. (Price 25s.)

This work deals with those aspects of metallurgy which are of the more direct importance to the engineer. The main outlines of the treatment include the following: The general relationship of the ferrous materials; steel, its composition and structure; ingots and ingot defects; the heat treatment of steels; the hot and cold working of steel; tool and case-hardening steels; cast iron; brass; bronze; aluminium alloys and bearing metals. The microstructure of the common metals and alloys is well considered and illustrated by a large number of photomicrographs. The mechanical properties at room and at high temperatures of the main engineering metals are treated at some length, and their relation to the treatment, composition, and structure discussed. Although specifically written for the engineer, the book will be of considerable service to students of metallurgy who desire an introductory general treatment of this side of metallurgy—namely, the properties and treatment of the metals after they have been extracted from the ores and suitably refined.

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